EPA

ADDITIONAL KEY CONTACTS

(Use as many sheets as needed.)

Major Co-Investigators: *Individual responsible for the completion of major portions of the proposed work.*

Name: Michael Barret
Title: Professor
Mailing Address: Center for Research in Water Resources
10100 Burnet Rd, Bldg 119 / Austin, TX 78758
Phone Number: 512-471-3131
FAX Number: 512-471-0072
E-Mail Address: mbarrett@mail.utexas.edu
Web URL:

Major Co-Investigators: *Individual responsible for the completion of major portions of the proposed work.*

Name: Fernanda Leite
Title: Assistant Professor
Mailing Address: Dep of Civil, Architectural and Environmental Engineering - The University of Texas
301 E Dean Keeton St / Austin, TX 78712-1094
Phone Number: 512-471-5957
FAX Number:
E-Mail Address: fernanda.leite@austin.utexas.edu
Web URL:

Major Co-Investigators: *Individual responsible for the completion of major portions of the proposed work.*

Name: A. Charles Rowney
Title: UWRI Secretary
Mailing Address: Urban Watersheds Research Institute
845 S Cove Way / Denver, CO 80209
Phone Number: 303-728-4449
FAX Number:
E-Mail Address: acr@rowney.com
Web URL: www.uwtrshd.com

EPA

ADDITIONAL KEY CONTACTS

(Use as many sheets as needed.)

Major Co-Investigators: *Individual responsible for the completion of major portions of the proposed work.*

Name: Emily Berglund
Title: Assistant Professor
Mailing Address: Dep of Civil, Construction, & Environmental Engineering - North Carolina State University
Campus Box 7908 / Raleigh, NC 27695-7908
Phone Number: 919-515-2338
FAX Number:
E-Mail Address: emily_berglund@ncsu.edu
Web URL: www.ncsu.edu/~emzechma

Major Co-Investigators: *Individual responsible for the completion of major portions of the proposed work.*

Name: Dan Ames
Title: Associate Professor
Mailing Address: Dep of Civil and Environmental Engineering - Brigham Young University
368 Clyde Building / Provo, UT 84602
Phone Number: 801-422-3620
FAX Number:
E-Mail Address: dan.ames@byu.edu
Web URL:

Major Co-Investigators: *Individual responsible for the completion of major portions of the proposed work.*

Name: Theodore Cleveland
Title: Associate Professor
Mailing Address: Dep of Civil & Environmental Engineering - Texas Tech University
Box 41023 / Lubbock, TX 79409-1023
Phone Number: 806-834-5101
FAX Number: 806-742-3449
E-Mail Address: theodore.cleveland@ttu.edu
Web URL:

3 Table of Contents

4 Abstract

4.1 National Center for Sustainable Water Infrastructure Modeling

a. Funding Opportunity: National Center for Sustainable Water Infrastructure Modeling Research, EPA-G2014-STAR-H1

b. Project Title: A Sustainable Center for Crowd-Sourced Water Infrastructure Modeling

c. Investigators: single Lead PI with co-PIs. Lead PI: Ben R. Hodges (UT); co-PI: Michael Barrett, (UT); co-PI: Fernanda Leite, (UT); co-PI: A. Charles Rowney (UT); co-PI: Theodore G. Cleveland (Texas Tech); co-PI: Dan Ames (BYU); co-PI Emily Berglund (NCSU);

d. Institutions:
University of Texas at Austin, Center for Research in Water Resources, Austin, Texas; Urban Watersheds Research Institute, Denver, Colorado; Texas Tech University, Lubbock, Texas; Brigham Young University, Provo, Utah. North Carolina State University, Raleigh, NC.

e. Project Period and Location: 9/1/2016 - 8/31/2021 Main hub: Austin; research: Provo, Lubbock, Temple, Raleigh; training/support: Denver; community input and service: nationwide.

f. Project Cost: $3,999,803 (total for all years, including direct and indirect costs).

g. Project Summary:

Objectives: Develop a sustainable Center for sustainable water infrastructure modeling, encompassing research, support and code development. Implement a community-based approach to model development and management that ensures water infrastructure model code is high quality and controlled, but advances and evolves based on crowd-sourced contributions. Improved model capabilities and modularization of code are immediate value-added outputs.

Description and organizational approach: A strong team and efficient approach will deliver dependable results. The men and women on the team are capable not only of the SWMM/ EPANET outputs, but any reasonable future water resources extension, including groundwater, economic, Big Data, biological, treatment and other analyses and elements. The well-established Center for Research in Water Resources at UT Austin and UWRI already provide proven, efficient, sustainable centers of research, software development and training, which directly leads to sustainability of the new Center. Professional management and support, modern software development and community infrastructure, coupled with academic excellence in research, under the guidance of an Model Expert Panel and Stakeholder Committees comprised of industrial (software, consulting, monitoring/control system), academic, institutional and regulatory members, with community involvement and EPA cooperation, will lead to a non-partisan, credible and effective community hub and production model. All teams competing for this project will be canvassed as candidates for participation in the Expert Advisory Panel proposed herein.

Expected Results: i) A sustainable Center as a hub for community and model development, maintenance, support, training, outreach and documentation. ii) SWMM and EPANET updated to a maintainable, linkable, extendable modularized format, with new biofilm, green infrastructure support modules and a quantum leap in code solution speed. iii) Ongoing training (classroom and online) supporting users and developers, and support system for all Center software, both funded by users. iv) Synergy between EPA, researchers, developers, users and software vendors.

h. Supplemental Keywords: watersheds, global climate, ecosystem, innovative technology, sustainable development, hydrology, engineering, infrastructure, data integration.

4.2 Subproject 1: Community Outreach and Support

a. Funding Opportunity: National Center for Sustainable Water Infrastructure Modeling Research, EPA-G2014-STAR-H1

b. Project Title: Community Outreach for a Sustainable Center for Crowd-Sourced Water Infrastructure Modeling

c. Investigators: single Lead PI with co-PIs. Subproject Lead PI: A. Charles Rowney (UT); co-PI: Dan Ames (BYU); co-PI Fernanda Leite (UT); co-PI: Ben R. Hodges, (UT); co-PI: Theodore G. Cleveland (Texas Tech);

d. Institutions: University of Texas at Austin, Center for Research in Water Resources, Austin, Texas; Urban Watersheds Research Institute, Denver, Colorado; Texas Tech University, Lubbock, Texas; Brigham Young University, Provo, Utah.

e. Project Period and Location: 1/1/2016 - 12/31/2020 Main hub: Austin; research: Provo, Lubbock and Temple; training/support: Denver; community input and service: nationwide.

f. Project Cost: $1,312,925 (total for all years, including direct and indirect costs).

g. Project Summary:

Objectives: The Center will be a community hub of a broad and loyal community, with a warm and communicative approach to encouraging entrepreneurial code contributions and a record of exceptionally effective outreach. It will also maintain a formal professional backbone of corresponding developers, ensuring a credible and QA/QC'd product line and an ability to collaborate professionally with industrial or other partners. Support, feedback and training will provide value to the community. A business model will contribute to sustainability of the Center by promoting an income stream based on value received.

Description and organizational approach: Advanced communications technologies will widen the Center's outreach, with code and outreach organized via a Model Portal providing a web-based service for open-source code sharing, community interaction, and a one-stop location for documentation, case studies and online model training. Training and support will be developed by professional staff at UWRI, who will organize courses, support QA/QC of code before release, and assist with monitoring crowd-sourced bug fixes. A unique strategy is to extend outreach to emerging data stakeholders. The Open Geospatial Consortium is developing standards for communications between data and models, critical to the long-term automation of SWMM and EPANET. The Building/Civil Information Modeling (BIM/CIM) communities are an untapped resource of 3D data inside buildings and below urban streets, but they use different geometrical models than the GIS familiar to EPANET and SWMM users. An outreach program will pull these disciplines closer together to enable technology convergence. Funds enabling sustainability will increasingly be obtained through subscription services and targeted support to industry and users, working in harmony with commercial providers, over the project.

Expected Results are: i) A high profile Center that is a sustainable hub for innovation, training, outreach, community engagement and support without continual injections of EPA funds. ii) A professional model development and support operation that has the confidence of industry, government, and academia. iii) A systematic approach to crowd-sourced code development with Center oversight and stakeholder control by Model Expert Panels. iv) A committed community of modelers. iv) Training materials, documentation, webinars, the Portal and a new journal adding to the body of knowledge available to modelers.

h. Supplemental Keywords: watersheds, global climate, ecosystem, innovative technology, sustainable development, hydrology, engineering, infrastructure, data integration.

4.3 Subproject 2: Code Development

a. Funding Opportunity: National Center for Sustainable Water Infrastructure Modeling Research, EPA-G2014-STAR-H1

b. Project Title: Model Development for a Sustainable Center for Crowd-Sourced Water Infrastructure Modeling

c. Investigators: single Lead PI with co-PIs. Subproject Lead PI: Theodore G. Cleveland (Texas Tech); co-PI: Ben R. Hodges (UT); co-PI: Michael Barrett, (UT); co-PI: A. Charles Rowney (UT);

d. Institutions:

University of Texas at Austin, Center for Research in Water Resources, Austin, Texas; Urban Watersheds Research Institute, Denver, Colorado; Texas Tech University, Lubbock, Texas;

e. Project Period and Location: 1/1/2016 - 12/31/2020 Main hub: Austin; research: Provo, Lubbock and Temple;

f. Project Cost: $1,179,545 (total for all years, including direct and indirect costs).

g. Project Summary:

Objectives: The Center will create clean code-versioned distributions of existing EPANET and SWMM along with test cases and documentation for use in training and as baselines for code modification QA/QC. New modularized versions of EPANET and SWMM will be constructed such that modules have independent communication interfaces and can be separately modified and compiled without affecting other sections of code. A new sub-segmented Eulerian transport model for EPANET will be constructed to provide capabilities needed for advanced biofilm modeling.

Description and organizational approach: The Center will use a systematic approach to refactoring (deconstructing and testing) existing code, then modularizing it into independent component environments that are easier and more robust for crowd-sourced programmers to use in adding new ideas to the models. This is because changes are confined to specific modules and can be undertaken without affecting other modules, and coders need not understand or modify the whole code to make useful changes, thus facilitating the innovation, bugfixing and long-term maintenance. Code development will be done by PIs with long and current experience in writing and testing code, assisted by scientists and graduate students (who will mainly conduct tests). All code will be created, cleaned, commented, and checked in a team-development environment. Standard test decks will be developed so that not only the current updates but future codes can be compared directly to the baseline legacy codes outputs for exactly the same input data. A code standard will be published to enable programmers to readily interact with the new modules. The development of sub-segmented Eulerian transport will use established scalar transport algorithms to allow spatial distributions of scalars created along a pipe length in EPANET. This is a necessary feature to allow biofilms to evolve along pipes in the advanced biofilm module being developed in the Novel Research Subproject.

Expected Results: i) New modularized models providing an updated and solid computational framework for EPANET and SWMM over the next 15-20 years of service. ii) Maintainable, modular codes eliminating the need to rebuild and test an entire model's code for each change, reducing the costs of innovation. iii) Modular codes that are more accessible to a broader group of programmers. (iii) A database of baseline model behavior providing the foundation for quality control checks of future code changes.

h. Supplemental Keywords: watersheds, global climate, ecosystem, innovative technology, sustainable development, hydrology, engineering, infrastructure, data integration.

Subproject 3: Novel Research

a. Funding Opportunity: National Center for Sustainable Water Infrastructure Modeling Research, EPA-G2014-STAR-H1

b. Project Title: Model Development for a Sustainable Center for Crowd-Sourced Water Infrastructure Modeling

c. Investigators: single Lead PI with co-PIs. Subproject Lead PI: Ben R. Hodges (UT); co-PI: Theodore G. Cleveland (Texas Tech); co-PI: Michael Barrett, (UT); co-PI: A. Charles Rowney (UT); co-PI Emily Berglund (NCSU);

d. Institutions: University of Texas at Austin, Center for Research in Water Resources, Austin, Texas; Urban Watersheds Research Institute, Denver, Colorado; Texas Tech University, Lubbock, Texas; North Carolina State University, Raleigh, NC.

e. Project Period and Location: 1/1/2016 - 12/31/2020 Main hub: Austin; research: Provo, Lubbock and Temple; training/support: Denver; community input and service: nationwide.

f. Project Cost: $1,184,476 (total for all years, including direct and indirect costs).

g. Project Summary:

Objectives: Without eliminating current solvers until the community is comfortable with the change, the Center will create alternative numerical solvers for EPANET and SWMM that will provide radically higher computational speeds for both desktop workstations and GPU processor technology. New capabilities for SWMM in Green Infrastructure and new capabilities for EPANET in Biofilms will be implemented. Needs, requirements and implementation approaches for security, real-time monitoring, and system sensor technology will be evaluated.

Description and organizational approach: The Center will focus on two areas of model advances that can be achieved with great benefit at manageable cost: improving/extending Green Infrastructure algorithms in SWMM and providing new Biofilm modeling capabilities in EPANET. A third area is production of a high-speed numerical solver based on recent approaches used in microprocessor design that have been extended to use in river network modeling. Over and above the specific Novel Research objectives, the Center will develop a sustainable approach to innovation that provides a systematic path linking the Center with stakeholders and external model experts in setting model needs and requirements, identification of correct implementation approaches, writing code, producing documentation, and validating code. A process by which future developments are overseen by the Center but can accomplished by a series of tasks distributed through the community will be established. One of the steps in this direction will be in working with the broader community in defining the needs, requirements, and implementation strategies for security, real-time monitoring, sensors and control in EPANET and SWMM.

Expected Results: i) A solid, high-speed, numerical foundation for EPANET and SWMM that will allow the models to be used for more extensive and demanding sustainability studies than is presently possible (e.g. Monte-Carlo simulations of large systems). ii) SWMM code for Green Infrastructure that is adaptable and extensible. iii) New capabilities for Biofilm modeling in EPANET-MSX and extended capabilities in the new modular EPANET with sub-segmentation and Eulerian transport (from Code Development subproject). iv) A documented path forward for implementing security, real-time monitoring, sensors and control features in EPANET and SWMM.

h. Supplemental Keywords: watersheds, global climate, ecosystem, innovative technology, sustainable development, hydrology, engineering, infrastructure, data integration.

5 Center Description

The objective of this program is to develop a sustainable Center for sustainable water infrastructure modeling, encompassing the three stated critical areas of research, support and code development. In achieving this, it is important that the program implements a community-based approach to model development to gain the substantial creative output of the modeling community at large. However it is also key that there be formal management approach that ensures water infrastructure model code is high quality and controlled, taking advantage of the inputs from the community but superimposing professional standards of code development, testing and documentation. This will require a balance of perspectives, but will lead to powerful results and a sustainable presence for the Center.

A Truly Multidisciplinary Program

In order to accomplish this, a range of skills and interests must be represented. There is, first and foremost, a need for water resources engineering and science skills to ensure that the fundamental subject matter knowledge is at the core of the team and reflected in its results. But at the same time, and just as important, is the need for skills in mathematics involved in the computational engine development, and for the ability to translate that understanding into professional level code. Coupled with these are the skills needed to implement the research sub-projects of interest in this program, including specific skills in biofilm behavior, infrastructure practices, GIS, building information management and potentially other topics.

Complementing these technical skills is a need to understand communities and how to interact with them, how to communicate complex topics, and a well developed ability to manage a team tackling complex projects in a distributed network over the long term, including an ability to comfortably understand and use the whole range of modern media for communication. Even with this injection of new communications demands, the ability to deliver traditional indicators of academic excellence will remain, since publications in journals and other standard vehicles for communication will be required if the full range of validation and participation by the community at large.

The realities of business and evolving practical requirements are also demanded as skill sets, since there is a need to anticipate the emerging uses to which SWMM and EPANET will be put and the ways in which industry will apply them. Much of this practical need is propelled by regulatory drivers, so a full understanding of emerging and current needs requires a strong capability to understand and apply the regulations and policies that apply to and sometimes dominate the physical contexts of the sites which these and other models are used.

Finally, it is important to acknowledge the 'soft' skills so critical to a successful community outreach program, the need to respect and interact with members so as to elicit positive responses and continued interest. So often overlooked in the heat of technical interests, this is paramount.

We have been careful to consider every avenue and skill set that may be encountered in the course of the program over the last five years, and have assembled a group of institutions, men and women from a range of geographies and backgrounds that can deal ably not only of the SWMM/ EPANET outputs, but any reasonable future water resources extension, including groundwater, economic, Big Data, biological, treatment and other analyses and elements. The well-established Center for Research in Water Resources at UT Austin and UWRI already provide proven, efficient, sustainable centers of research, software development and training, which directly leads to sustainability of the new Center. Professional management and support, modern software development and community infrastructure, coupled with academic excellence in research, under the guidance of a Model Expert Panel and Stakeholder Committees comprised of industrial (software, consulting, monitoring/control system), academic, institutional and regulatory members, with support and cooperation from EPA, will lead to a non-partisan, credible and effective community hub and production model.

Integrating the Elements

The Management Measures – Nevertheless, it is important to manage this program in a way that acknowledges differences in approach and capitalizes on variations in experience. We have provided focus without building silos by setting up the following mechanisms:

1. The research elements of the program are centered at the contributing universities, and the business elements of model deployment, support and training are centered at UWRI. Each group does their assigned activities very well.

2. We have selected partners in research skilled in the particular areas we propose to examine. Our representation in GIS, BIM, biofilms, and SWMM / EPANET in particular is outstanding.

3. Our team boasts backgrounds not just in academia, but in business and municipal practice.

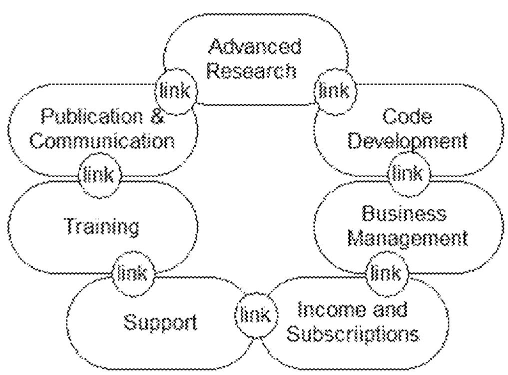
4. We have selected in favor of individuals who have an outstanding record in community development and institutes and societies.

5. To ensure that the above specializations do not degrade into silos, we have set up a management team with a balance of science, engineering, academic and business experience.

6. To further knit the teams together, we have identified management measures that will ensure the various participants are motivated to remain in synch. For example, the code development we propose will lead into the application of new engines and capabilities. To make this work, both teams need to interact early and often. As another example, the training and support arm of the program, in UWRI, is linked to the research arm not only by a common understanding of the problems to be solved, but by individuals selected to play a role in both sets of activity.

The Program Links – The development elements of our program are all interdependent, and this is not by accident. It is because we began by considering the fundamental objectives of the project, and then devised an integrated whole that would efficiently develop the needed results:

- The development of code links to advanced research by common core of code requirements.
- The advanced research links to the publication and dissemination with a conscious focus on promulgation of the outputs of research.
- Publication and dissemination spans not only the research outputs, but the primers in how to use SWMM and EPANET, and everything in between.
- The users of models are not only supplied with training and information, there is support available to them.
- The support and training are not only supported initially by the research funding applied by EPA, but by user subscriptions and independent income streams.



- The ability to develop income streams and subscriptions, and professionally manage the program so it is sustainable, requires experience and business acumen.
- The ability to drive the sustainable business elements of the program forward demands a close link with the research and code development arm of the enterprise, so that the products that emerge are consistent with what the community needs.

Clearly the above train is an interdependent system, in which every element benefits from excellence in the others. This team is aware of this, enjoys the opportunities to interact in the way this program is planned, and has worked together in these ways before. The linkages and understanding brought to bear will make manageable even a project as complex as this Center.

A Vision for an enduring Center

Even with the above tangible links, there is an ethos that will be needed to make this system work as the realities of a challenging program make themselves felt.

A Service Ethic: In a strong and systematic partnership with EPA, the proposed National Center for Sustainable Water Infrastructure Modeling (*the Center*) provides three key Services:

- *Service to municipal governments, NGOs, and academics:* provides open-source access to tested models, decision support, and control systems for a sustainable water infrastructure,
- *Service to modelers:* delivers a sustainable infrastructure for crowd-sourced development, adaptation, testing, and publication of models, decision support, and control systems,
- *Service to industry:* research, support and development in keeping with EPA's mission in a way that respects the abilities, needs and contributions of the WR industrial community.

The three pillars of **Research**, **Community Outreach**, and **Code Development** are aligned with this three-fold service ethic in a sustainable enterprise: outside investment follows from both perceptions and actual delivered benefits – which are inherently services for open-source models. We are focusing the EPA's targeted scope within a service-oriented, nonprofit enterprise that directly involves the modeling community to deliver benefits to all parties.

A Hallmark Identity: The Center is the hub for developing and distributing software supporting WR infrastructure. It is where excellence in computational and software engines can be tapped by users, regulators, and industry alike. It is where learning, support, and community interaction are sought, found, and encouraged. It is where leadership in practice meets the state of the art. It is the public face of WR analytical capability in the USA. It is where WR professionals across the country feel a sense of ownership and participation, where their contributions are acknowledged and rewarded and built upon by others. And it is where professionals can find support to handle evolving issues in WR modeling and management.

An Adaptive, Reality-Based Approach: Achieving a sustainable Center requires a pragmatic balancing of many factors. The information technology and management (IT/IM) context is challenging as there are major competing forces. Connectivity and cloud technology must mesh with an increasing emphasis on security; industrial interests and proprietary technologies co-exist with free and open source solutions and communities; increasing modeling sophistication is emerging at the same time as data exchange and storage are advancing. Our strategy is to embrace such forces not only as they are today, but adapt as they evolve into the future.

A Commitment to Professionalism: The Center meets the needs of the community and the requirements of the RFA by capitalizing on the unmatched creative energy, academic excellence, and production ability of the professional community that regulates, develops and manages our water infrastructure. Professionalism in management coupled with the power of the community is requisite for success.

A Commitment to Community: This Center will not be a closed fiefdom. The historic software represents not just the leadership and expertise of EPA, but the culmination of decades of contributions and support by a community of academic, government, and industry professionals. The Center is committed to sustaining this support base, experience, and community through creative crowd-sourced approaches to software development. And we will do so in a fully neutral and effective way. All teams competing for this project will be canvassed as candidates for participation in the Expert Advisory Panel proposed herein.

Expertise of the team

This project will be organized by a Lead PI and 6 co-PIs, with an additional staff of senior personnel who will address specific task. Note that may of the tasks will be lead by co-PIs or the Lead PI to ensure that the project does not have too many leaders and not enough workers.

Dr. Ben R. Hodges, Lead Project Investigator, has an extensive history of developing new and innovative algorithms for hydrodynamic modeling in 1D, 2D and 3D. He brings to this project the innovative approach used to apply solution methods for electronic microchip circuitry to river network models, which will be adapted to EPANET and SWMM as part of this project.

Dr. A. Charles Rowney has a strong record in enterprise management as well as software development in general and experience with SWMM and EPANET in particular. He is adept at interacting with communities of practice, and currently serves on the Board of the Environmental and Water Resources Institute of ASCE as well as the Urban Water Research Institute. He was involved in the assembly and launching of the team that created SWMM 5, and facilitated the development of MIKE-SWMM (a SWMM front end and extension offered by DHI). His experience with models in the enterprise extends from development of a range of tools, to implementation of data plans and information management at an enterprise level. At one time a Division Manager of an engineering enterprise, he also has well developed skills in business practices that are fundamental to the professional and effective management of the new Center.

Dr. Michael Barrett is a national leader in the evaluation of urban stormwater management practices and has over 30 peer reviewed articles on this topic. He has extensive contacts in the stormwater arena, with past positions on the ASCE/EWRI Urban Water Resources Research Council and the Transportation Research Board Hydraulics, Hydrology, and Water Quality Committee. Dr. Barrett is currently serving on the Water Environment Research Foundation oversight committee for the International BMP Database and was awarded the Arthur M. Wellington Prize from ASCE for his work in stormwater research. In this project, he will guide the development of new algorithms to represent the expanding number of green infrastructure practices and use his list of contacts to help create a community of stormwater modelers.

Dr. Fernanda Leite, Urban Water Infrastructure Data Task Leader, works in the area of building information modeling (BIM) for design and construction. She is currently working on extrapolating concepts of BIM and applying them to Civil Infrastructure. Her long term motivation is developing digital representations of the physical world, which can enable a broader vision of smart cities. In this project she will bring this expertise to work on a test-bed model of part of the UT campus to examine how piping infrastructure in and around buildings can integrate with the data needs for EPANET and SWMM.

Dr. Theodore G. Cleveland, Code Development Lead, works in the area of hydrology and hydraulics modeling and development of web-delivered models. He brings to the team prior experience in building web-delivered software (ANTS and JAMINLAKE are examples of early web-based scientific programs – no longer available but pioneerd hybrid server-workstation processing) and wireless database access (pre-dating smart phones). He is extremely familiar with EPANET and SWMM5.

Dr. Daniel P. Ames has a substantial track record of organizing open source software development communities in the environmental and water engineering and modeling domain. The open source MapWindow GIS software has a worldwide user base with over 6000 new downloads per month and 20,000 members of an opt-in mailing list. The HydroDesktop project is an open source desktop front-end to the CUAHSI Hydrologic Information System, which provides web services based access to over 80 distributed services of water and climate time series observation data. Additional active open source software projects and communities developed by Dr. Ames include HydroServer Lite, PVMapper, and MAD, all of which can be found on the open source portal, codeplex.com. Dr. Ames will use this expertise to help create the Center's proposed Model Portal for EPA models.

Dr. Emily Berglund (née Zechman) is an expert in water infrastructure security and source tracking, who has been researching and publishing extensively in this area. Indeed, outside of staff at EPA and Sandia National Labs, she is one of the most-published US academics in this area and is ideally positioned to lead the study in these areas.

In addition to the expertise of the PIs, the Center will have access to a variety of expertise through UWRI and the research faculty at UT. Beyond that, we have provided a link with, and a commitment to, professional firms with professional programmers who will ensure that professional practice in coding, testing, documentation and support is applied as appropriate as these core technologies are made available to users around the world.

Because of the expertise required in working with model code, much of the coding work will be done by PIs Hodges, Cleveland, and Rowney, with assistance of post-doctoral scientists.

The team provides the unusual breadth of coverage necessary for development of the Center. On one hand, it boasts a team of academics with a truly outstanding and recognized record of accomplishments in relevant research On the other hand, it is a team of professionals that encompass the range of functions from professional code development through to business development and enterprise management that will be key to a long-term sustainable Center. Further, the breadth of individual capabilities is echoed organizations housing the individuals. The CRWR has a long term and acknowledged record of success as a leading edge water resources research facility; UWRI has a long term record as a first rate, self funded and sustained non-profit supplier of expertise, software and training to the water resources community. Knitting this range of capabilities together is the personal mutual regard of the management team, who have worked together to good effect for years. In so doing, the management team has developed a record of seamless collaboration that guarantees these different perspectives on the team will be complementary, and not lead to conflicting efforts in the Center. The records and dispositions of this leadership team also guarantees that a strong working relationship with EPA will be sought and achieved under the aegis of the Cooperative Agreement.

Section 6A: Community Outreach and Support (Subproject 1)

This project will provide:

- A strong user and contributor community, and a sustainable supporting Center.
- A web-based Model Portal for crowd-sourced community coding and interaction.
- Outreach, training and support to industry/academia/government with a business plan for long-term financial sustainability of the Center.
- A new Journal of Water Infrastructure Modeling run by and for code writers/users as a way to publish code, algorithms, test cases, and documentation.
- Collaboration with the Building/Civil Information Modeling community and Open Geospatial Consortium to develop data exchange approaches and standards

1 Motivation, Goals, and Objectives

The motivation for this subproject is the need to identify, mobilize and support a vibrant and self-sustaining community of model developers, users, and water infrastructure professionals interested in EPANET, SWMM, and future models.

Subproject Goals

1. Provide a systematic approach to maintaining and distributing model codes.
2. Develop and encourage participation of a broad user community.
3. Provide the organizational and technical tools to document, integrate, and encourage contributions by programmers and model users.
4. Reach these goals in a way that is sustainable over the long term with relatively little financial input from the Center.
5. Develop a sustainable business operation for the Center that obtains funding from industry, state/local governments, and NGOs

Our specific goals are listed to the right. To meet them we will create a user and developer community using mechanisms adapted from proven models in the Free and Open Source Software world (e.g. the Linux and *R* communities). We will couple the raw power of the vast creative community of model users at large with a central cadre of professionals equipped to turn widely varied ideas and contributions into an effective professional capability.

To do this, we will allow public access to the most current stable distributions and legacy distributions of models supported by the Center, so that developers can readily modify the stable code by forking or branching[1] a particular component to meet their needs. We will also work to capture the results of this entrepreneurial development by tracking activity, motivating sharing, and developing collaborative relationships. But the outputs in the form of code and modeling insights arising from this outreach will be balanced with a centralized system that enables professional QA/QC, version control and other attributes of professionally founded tools. In this way, the Center will not only reach out to users, but will help channel their outputs to create solid, dependable, professional successors to the present SWMM and EPANET models. The motivation and goals lead to clearly-defined and measureable objectives that will be met by the Center (see box on following page).

[1] Forking and branching refer to somewhat similar operations – in the first the user creates his/her own repository of the code to modify; in the latter the user works with a branch in the main repository.

Objectives

1. Create an implement a **Business Plan** to ensure the Center operates with specific assigned resources, outputs, procedures and income stream expectations, in a way that will guarantee implementation of a sustainable Center that achieves the objectives set forth by EPA.

2. Use modern, proven and innovative communication methods to reach out, gather resources, and engage stakeholders. Among them:

   The **Model Portal** (web-based system) will be implemented for code source control and crowd-sourced collaboration.

   A series of **Workshops and Training** programs will be conducted to encourage community building, outreach and education.

   The open access **Journal of Water Infrastructure Modeling** will be created, which encourages submissions of code and documentation will be developed.

3. Enable outreach and collaboration with **Building Information Modeling** community and the **Open Geospatial Consortium** to ensure advances in EPANET and SWMM can take advantage of and help drive evolving data standards.

2 General Approach and Activities

Figure 6A-1 depicts the general factors we see as critical to success.

- The Center itself must be sustainable and professional, and this need will shape its approach to research, development, support and interaction with users.
- The Center must use a wide range of mechanisms, from traditional journal publications (we plan to introduce a new Journal!), to organized web portals (we will deliver a major community Model Portal), to every reasonable media the emerging community of modern modelers expects to use.
- The Center must be developed from the outset with a determination to envelop every stakeholder.

The following sections discuss the key mechanisms we will use to accomplish the outreach and support subproject.

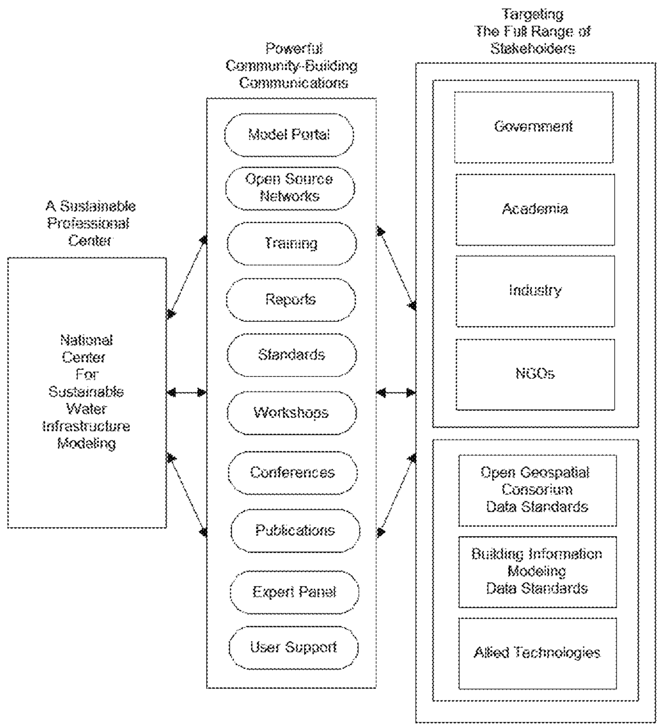


Figure 6A-1. Outreach and support provided by the Center.

2.1 Summary of the Implementation of a Business Plan

The Center is to be self sustaining, and this requirement by itself is sufficient to make it clear that enthusiasm and creative energy are not enough for a successful program. A backbone of experienced professional experience in business practices will be necessary to develop a service model and funding stream which will in the long term be the sustainable income model for the Center. To rely on grants, donations, or potentially mercurial handouts from industry is to invite long term erosion and failure. Outreach, therefore, must have two axes. On one hand, the enthusiasm and creativity of the modeling community will, as it has for so long, emerge as a key mechanism for a sustainable future. But on the other hand, outreach in the form of a user pay model which provides professional services for training and support will, as an innovative element of this Center, lead to an income stream that will pave the way to a robust future. By the end of the 5-year EPA funded program, we are determined to have the Center effectively run community outreach, training and support components, and its core cadre of staff based entirely on fees generated by the Center itself. Our link with UWRI is a key element of this strategy.

2.2 Summary of a web-based *Model Portal* for crowd-sourced collaboration

The Center will develop a *Model Portal* to serve as a comprehensive community-based access point for EPANET and SWMM, including variants of these models and future model developments. The system will provide capabilities to formally manage and control documents, but will also enable ad hoc posting and queries by community members. We have concluded that the Model Portal will be composed of a suite of tools, thematically branded in a common way, and accessible through a common interface, but including several 'best of breed' components serving the range of needs the Center will develop. The Model Portal is discussed in detail in §4 below.

2.3 Summary of workshops, community support, and training programs

The Center will host annual workshops at UT (participant support is included in the budget) for model programmers and users in the community to discuss developments and help guide the Center. Through UWRI, we will develop training programs and online/on call technical support for the model (see discussion in §3.2 on training/support as a source of external funding). A principal aim will be to develop training and online documentation for use of the Model Portal, so that users can learn to access compiled models, documentation (including source code), and demo file sets in a convenient way; escalation to other features will also enable bug reporting and code submissions. We are experienced in the development of training videos and webinars, and within the limits of the available budget believe that a first priority to consider is development of a SWMM101 and EPANET101 webinar which will be recorded and available thereafter.

2.4 Summary of the Journal of Water Infrastructure Modeling

A challenge for crowd-sourced modeling is that "high quality model code is often a secondary priority since scientific reward is frequently based on the accuracy of model output, rather than the long-term model code maintainability and sustainability," (David et al, 2013). Although QA/QC management will ensure that distributed code meets best practices, the Center must encourage developers to make the extra step of fully communicating their contributions and experiences. Formal reviewed publication is a proven positive element of this; a journal, integrated into the code development process, can address issues associated with inadequate documentation (Guillaume, 2011). We will address this by establishing the *Journal for Water*

Infrastructure Modeling (JWIM) with a focus on publishing details of model structures and code in a rigorous fashion, encouraging professional practice in this area, as a complement to the QA/QC process. JWIM will be established as an electronic open-access, fee-based publication using Ambra. The journal will also link with GitHub so that modelers can write papers that explain the functioning and structure of the model code with direct links to the code itself.

2.5 Summary of Water Infrastructure Data in Building Information Modeling and the Open Geospatial Consortium

Collaboration with people is not enough. Data interchange is also a key driver. Links based on development of data and model interoperability standards will be critical to the long-term sustainability of EPANET and SWMM models. Building Information Modeling (BIM), which includes data modeling for 3D building piping installation, uses different data standards than the traditional GIS and network approaches used in EPANET and SWMM (BuildingSmart 2014a,b; GSA 2014; USACE 2014). Furthermore, there are presently efforts within the Open Geospatial Consortium (OGC 2014a,b) working on new data standards for Smart City / Smart Grid (OGC 2014c), piping systems (OGC 2014d) and land representations (OGC 2014e) that are necessary for both models

To develop systematic outreach between these areas, the Center will work to (i) develop data model and interoperability methods to link BIM and EPANET for modeling flow and water quality in building distribution piping, and (ii) lead and participate in working group activities of OGC that will engage the water infrastructure community of agencies, industry and academia with EPANET and SWMM. This will include a city scale testbed project (for details see §5).

3 Detailed Approach and Activities for the Business Plan

3.1 Overview

The Business Plan tasks, products, and outcomes for the Center and the broader community are provided in accompanying boxes, and this section describes our approach to coordinating the user/developer communities, and committing to a staged implementation allows continued operation of the present SWMM / EPANET models. We also show how we will start seeking external funding from the program inception to ensure that core missions of training, support, and code development will continue in a self-sustaining manner in Year 6 and beyond. The concluding Business Plan discussions discusses how the Center will evolve its operation over this period.

Business Plan Tasks

1. Create a business development organizational structure.
2. Develop and implement training programs for SWMM and EPANET.
3. Develop and implement support services for online and call-in by users.
4. Arrange funding mechanism for User Subscriptions and other external funding.
5. Outreach and publicity to engage the community in support and training.
6. Update training/support materials and provide publicity for launch of modular SWMM and EPANET in year 4.
7. Ensure that income sources match Center expenses by the end of Year 5.

3.2 Centralized control without regimentation

The essence of this program is to motivate and mobilize the user community. A program based on central imposition of certain solutions would have some advantages, but would be likely to alienate some resource centers or personalities, and limit what can be accomplished. The Open Source world is replete with examples of 'forks' in software that result from inadequate attention to this factor. Therefore, a balance is needed. For things like QC standards, documentation and version control, a firm central authority is needed. But for entrepreneurial development of innovative interfaces, or analytical tools, or even alternative solution engines, speculative individual investment can pay off and should be encouraged – provided that all products released through the Center are tested for technical integrity, fully documented, and fitness for purpose.

Business Plan Products and Outcomes

1. Training materials for SWMM / EPANET.
2. User Subscription contract forms.
3. Operating online and call-in support services.
4. Publicity plan.
5. Annual review of external budget and expenses with future projections.

Operational control will be through the Center's leadership team. Outreach priorities and strategic development will be managed with the advice of an Expert Panel, convened annually to review results and make recommendations.

Model development tasks will be crowd-sourced, with rewards/incentives provided for contributions and collaboration. A strong quality control mechanism will be coupled with a "guided evolution" approach, ensuring only best of breed and validated contributions are endorsed by the Center.

To achieve the needed balance, the Center will provide a strong backbone to direct resources, but will use a *light-touch centralization* approach (see box) to outreach and engagement that develops a self-sustaining community.

Overall control will be through the Center's Executive Committee that is responsible directly to EPA for overall objectives and program funding, and accountable for results. This team interacts with a number of entities, each with a distinct function. Model Expert Panels and a Stakeholder Committee will assist in reviewing research proposals, and provide input on emerging technologies, goals and directions in industry. The Center will oversee RFPs for projects to address issues consistent with the Cooperative Agreement, with input from the Model Expert Panels. These may include research into areas such as biofilms, security, sensors, interface enhancements. Our proposal specifically some topics for consideration, but we will engage in broad community discussions over research priorities consistent with the Cooperative Agreement at the initiation of the Center. The process for managing research projects is discussed in Section 10 Administrative Unit (pg 64) and Section 7 Quality Management Plan (pg 55). The Community-at-Large will interact with the Center through the Model Portal (§4) as well as workshops, training, and user support (§2.3).

The Center will focus its long-term services based on the desired user support, with the initial EPA funding providing the bridge to develop the systematic links and bring this vision to reality. This funding model is crucial for continued model support based on user subscriptions rather than relying on routine injections of added research or operating funds.

Although our crowd-sourced approach will provide rapid innovation, to deliver professional results in a subscriber framework professional code developers are needed. We have available a pool of industrial partners through UWRI that will ensure code is developed and documented to modern professional standards and using the Center's interface protocols. We have worked with prominent vendors to identify mutual interests, and believe that positive relationships can be developed without conflicting with private sector imperatives. Indeed, we foresee that the bulk of this activity would be drawn from staff from private sector enterprises with an interest in the subject. A number of vendors have produced tools based on, or extended from, SWMM and EPANET already, and this has created a climate of understanding and mutual benefit that the Center can build on.

Similarly, to deliver professional support, professional skills are required. In the same way as professional staff of UWRI will be seconded to the Center for code development as discussed above, they will be made available for support of user queries and help requests. A system of online resources will keep the demand for this services to a supportable level, but eventually a human on the web chat line or even phone can make a world of difference in guiding user requirements. Excellent examples of this support model can be found not only in current software offerings, but in the service industry that provides hosted internet solutions. For training functions, we have been in contact with industrial partners assisting in this submission, and we believe a synergistic and effective partnering can be implemented, consistent with the role of the Center as intended by EPA. These services will be supported through external funding through user subscriptions and other sources (box at right). We anticipate that targeted research and model development will be funded from time to time by industrial sponsors or other sources. This Center will boast outstanding service capabilities, and strong links to first rate research programs, and can deliver when the need arises.

External Funding Sources

User Subscriptions for training will provide a key source of funds for sustaining the Center. An informal poll among potential participants and experience in similar ventures indicates that such funding will create a positive income stream. Our UWRI team has long-term experience in training and support, delivering high quality at a reasonable price for a needed service.

User Subscriptions for support and technical assistance will target organizations who need more direct assistance than available through the community networks.

Contracted customized model development for industry and government can turn crowd-sourced model developments into professional code.

Biennial conference fees and journal fees will be used for self-sustaining operations.

A key point is that the above set of interactions (support and income generating functions) are not high risk strategies. Support can be scaled to income, and targeted research will be operated as a non-profit extension of the Center. By implementing a balanced and appropriate set of relationships with professional entities, suitable skills can be acquired without committing to added staff, and private sector relationships can be forged which are consistent with private sector needs, government responsibilities and strictures, and the non-profit nature of the Center.

3.3 Staged Implementation and Legacy Code Sensitivity

The Center will be implementing code changes, and in order to avoid alienating potential partners and their traditional user base, these changes will need to be implemented by degrees and with sensitivity to prior investment. There are a range of models or modeling tools based on SWMM and EPANET, and it is a responsibility of the Center to implement changes in a way that will not be needlessly destructive. To ignore this reality is to invite splintering of the community, and potentially event 'forking' (in this case, that is to say the development of competitive products closer to legacy versions). The development of the Expert Panels, representing the range of industrial, academic and regulatory stakeholders, will do much to draw attention to this issue, and to moderate swings with potentially unfortunate consequences. However, there are some specific management measures that will be employed to ensure that staging is suitably implemented. The overall approach is shown in the box at right. Note that all model code is considered "data" for the purposes of the Data Management Plan and will be permanently and publically archived in the UT Data Repository (Section 9 Data Plan, pg 61).

Staged Code Modifications

Legacy capabilities will not be diminished. Present models will be maintained on the Model Portal with a code versioning system (see §4 below and Section 6B Code Development, pg 25)

New code releases will be both in stable Long Term Support (LTS) versions, and incremental releases to make rapidly available emerging features.

LTS of current models would be active up to year 4 of this project, with new incremental versions in years 2 and 3, and a new LTS in year 4.

Older LTS versions will continue to be available as deprecated code (i.e. available, but not supported with bugfixes or updates to new operating systems).

This pattern of LTS, incremental releases, and deprecated model availability will be continued for the life of the Center.

3.4 Implementing a Staged Funding Balance

At the end of this contract, it is important that the new Center will already be self sustaining. Our business model lends itself to addressing this need through a balance of services offered and user subscriptions or contributions, supplemented (but not dependent) on injections of research funds to respond to emerging needs. To build a sustainable Center, we intend to implement and develop the training, support, and subscription functions from the outset of the Cooperative Agreement in the staged approach shown in the box below.

Although the community outreach program will grow continuously over time (larger communities, a greater body of knowledge on line, continued support of code development) the

Expected Staged External Funding for a Sustainable Center

Years 1-5: Baseline funding for Research/Code Development/Outreach and Support are through EPA and are approximate balance (see this proposal Section 10: Administrative Unit)

Years 1-3: Additional income generated by support and training, expected to be 10% of costs in first year, to 30% to 40% by year 3.

Years 4-5: Subscriptions for support on new modularized code and external funding for targeted code development are expected to rise to 90% of costs by year 5.

Year 6 onwards: Core functions of code development, support and training will be supported by external funds. Targeted research supported by external grants.

need for funding will be modest after the initial EPA funding is used to create the Model Portal. Likewise, as the Center moves in Year 6 to being dominated by crowd-sourced innovation, rather than in-house research and code development, the administrative costs of the Center will precipitously decline. The ongoing outreach and Center administration will be readily funded by overhead charged on the support and training functions.

3.5 Parsimony without Compromise

The emphasis in management will be to ensure that all aspects of the Center are parsimonious in allocation of resources to internal operations, and focused on investment in production. Use of the established resources of the Center for Research in Water Resources at UT and UWRI will have a multiplier effect in that established, efficient teams and practices well versed in the specifics of the new Center will be engaged to best effect. The mission of UWRI as a high quality, low cost, professional provider of training and software is a natural fit to the current program. Taken together, we believe that the ability to minimize costs without compromising quality is, in this team, exceptional.

3.6 Planning Evolution from the Outset

Although considerable attention has been paid to the initial support of SWMM and EPANET in this proposal, we recognize that these models may not be the end point. It may be necessary to enable support of allied models and technologies, depending on the needs of the modeling community, model users, and industry. This team has considered this requirement from the outset. The business partners and internal staff have expertise far beyond SWMM and EPANET, including Big Data, groundwater modeling, optimization and control, hydrodynamic modeling, Green Infrastructure, water quality, and a wide range of other competencies.

The Center activities are scalable and adaptable. The initial 5 years of funding will build a core Center infrastructure that can be readily scaled by setting up new community networking sites, new data repositories, and new training courses and support teams. Every element of this program lends itself to extension and adaptation as needed. The funding model is also elastic. If, for example, a new open-source model is developed within the community, it is likely that only modest funding (developed through external funding sources, above) would be needed to extend the business model.

The management model is robust. Composed as it is from a team of industrial and academic partners, and with management input from Expert Panels that are extendable to wider interest areas and memberships, the basic structure of the Center will be readily adaptable to changing suites of models as driven by the needs of the community. The Center will expand to other models by allowing other model communities to develop committees and Model Portal code hosting under the Center's aegis.

4 Detailed Approach and Activities for Crowd-Source Model Portal

4.1 Overview

Community development is integral to the Center, and our approach to long-term model development and community collaboration can be described as "crowd-sourced". This approach does not require a team of centrally-controlled model developers, but progresses as model developers work on code modules as best suits their particular needs. Through the Center, modelers will find it easy and advantageous to share their code modifications, test cases, and data. The popular *R* statistical modeling software is an example of successful "crowd-sourced" development (R Team 2008).

The key to developing this community is in a code structure that can be readily understood and adapted, and a supporting infrastructure. The Center will organize a web-based infrastructure for crowd-sourced coding using the GitHub platform, which provides web-based control of open-source code development serving a community of users working across Windows, Mac, and Linux platforms. GitHub is a "social coding" (Begel et al 2013; Thung et al 2013) software development and management tool that is free for open-source projects. GitHub uses an archiving approach that allows many developers to work on the same code concurrently, but change merging can still be controlled by the Center. This system allows all users to immediately try out model variants developed by others, with full knowledge of QC state and release status. Research in collaborative software development has shown that using version control and configuration management system reduces the complexity of coordinating development (Grinter 1995,1999; Cheung and Lee 2010). Community-based model testing has also been demonstrated in other software engineering areas (Howison et al 1999; Crowston and Howison 2005; Bird et al 2007). In our project, our hub for community collaboration will be the *Model Portal*. The tasks, products, and outcomes for the Model Portal are shown in the accompanying boxes and are detailed in the sections below.

Model Portal Tasks

1. Create the ***Model Portal*** framework supporting EPANET and SWMM (§4.2)
2. Develop a ***Community Communication*** system within the Model Portal to encourage community input of issues, feature requests, bugs, suggestions; provide tracking and publicize new code contributions (§4.3).
3. Develop a ***Case Library***, a system for accepting, organizing, and sharing user created model input and parameter files for user scenarios, test cases, and validation data (§0).
4. Provide a ***Documentation Library***, a system for both official and community-contributed documentation in an organic, extensible format (§4.5).

Model Portal Products and Outcomes

1. Technical Report documenting the web-based implementation of Model Portal
2. Technical Report documenting the web-based implementation of the Community Communication System
3. Technical Report (User Guide) for Case Library
4. Technical Report (User Guide) for Documentation Library

4.2 Task 1: Create the Model Portal supporting EPANET and SWMM

We will engage with EPA, model developers, and users through direct inquiry to identify the most important potential uses and needs for a Model Portal. This will draw on existing experience with the development of similar portals to ensure that all needed functionalities are identified for inclusion. This task will principally involve a combination of creating new web portal codes and integrating existing codes to prepare a system that meets community needs. At a minimum we anticipate including a code versioning system, a documentation management system, a download manager, and an issue/bug tracker. Additional capabilities are likely to evolve from discussions with EPA and the community. A goal within this task is to create a generic Model Portal that is later customizable to other models. The Model Portal will go public using the existing versions of EPANET and SWMM, as described in Section 6B Code Development (pg 25).

4.3 Task 2: Develop a *Community Communication* system

The Model Portal will include an Issue Management System (IMS) that allows users, developers, and third party interested persons, to contribute information, suggestions, feature requests, comments, bugs, and potential issues to an open, searchable, well-preserved database. This ensures user input is not lost, and that it is visible to users their ideas and needs are heard. We have had excellent results with the open source Mantis system and see no need to resort to commercial alternatives, but are prepared to work with EPA in the event that alternative technologies are preferred.

4.4 Task 3: Develop a *Case Library*

The Case Library will provide a space that users can voluntarily share their model data sets, but more importantly will also provide a durable archive under the University of Texas aegis that Federal, State, and Local agencies can use for contractual and long-term archiving of model and data sets. The Case Library will be a system within the Model Portal for accepting, organizing, and sharing user created model input and parameter files for user scenarios, test cases, and validation data. This will allow for the sharing of model input and parameter files such as a calibrated model for a particular scenario in a particular geographic setting. The system will include the ability to: (i) upload and download files, (ii) provide comments and feedback on model file sets, and (iii) link file sets to publications. User cases will be documented with consistent metadata and electronically filed for retrieval and indexing. The community will be able to give ratings to different cases (e.g. 1 through 5 stars), which will help future users find the most useful cases, providing a useful management metric.

4.5 Task 4: Provide a *Documentation Library*

The Documentation Library within the Model Portal will provide a systematic approach to archiving and making available both official and community contributed documentation. Each model will have a community-edited Wiki document. Editors of specific wiki pages will initially be from the Center participants, but we will solicit volunteers from the community to take on editing duties and devolve supervision of this effort to the Model Expert Panels (Section 10 Administrative Unit, pg 64). User manuals and programmer guides will be approved by the Model Expert Panels through the QA/QC process (Section 7 Quality Management Plan, pg 55) and stored in the Documentation Library.

5 Detailed Approach and Activities for Water Infrastructure Data in Building Information Modeling

Co-PI Fernada Leite will lead a task to develop the linkages between Building Information Models, EPANET and SWMM using the Digital Austin Testbed Area that she has already been documenting (Figure 6A-2). The task and products are outlined in the accompanying box. Current data available are in GIS (*xy* data) and a surface model (lidar data). We will to acquire accurate Z-values for storm and water distribution lines. Available data sources include 2D drawings with annotations provided to us by UT Facilities. Additional data will be collected in the field by accessing manholes.

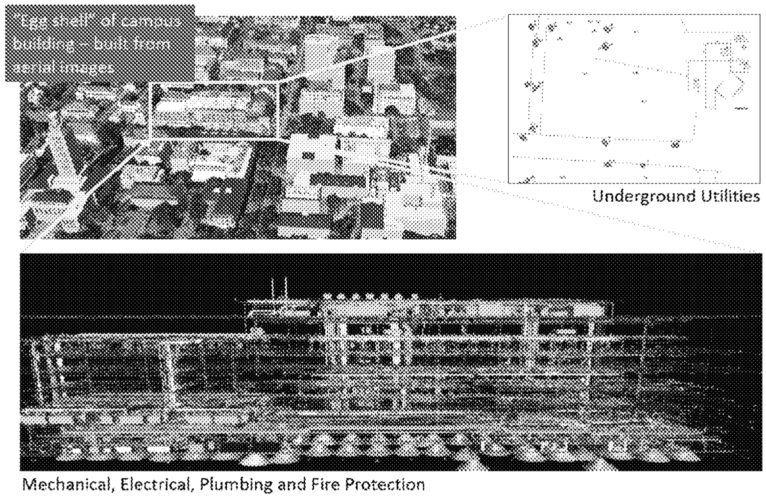


Figure 6A-2. Connecting digital representations of the building exterior, surrounding infrastructure, and interior mechanical/electrical

By integrating GIS model with lidar surface data and field surveys we can improve Z-value estimation of piping infrastructure. We will create geometric model storm and water distribution lines in Testbed Area using Autodesk Civil 3D. These formats integrate with existing Building Information Modeling systems, which can be generated in Autodesk Revit or in other BIM software and imported into Civil 3D as an IFC 2x4 or LandXML file. We will investigate how a BIM and Civil Information Model can be integrated. Interface management of existing BIM model and CIM modeled will be developed. We will investigate what data is needed from a BIM model to meet requirements of EPANET and SWMM and how we can extract it and export it. Finally, we will map CIM and BIM data (that is identified in Task 3) to EPANET and SWMM. Co-PI Leite's team will work with co-PI Cleveland, and OGC senior personnel Dr. Arctur to develop the semantic structure for mapping and present to the OGC.

BIM Linkage Tasks/Products

1. Collect Testbed Area geometric data and integrate with lidar data and GIS (product is a data set)
2. Create geometric model of stormwater and water distribution lines in Testbed Area (product is a data set)
3. Import sample BIM model for a single building in Testbed Area to examine connections between BIM and Civil Information Model (product is data set)
4. Create sematic mapping from Civil Information Model to EPANET and SWMM data structures (product technical report.

6 Detailed Approach and Activities for Water Infrastructure Data in the Open Geospatial Consortium

The Center will organize a Data Integration Steering Committee of key people (both within and outside the Center) with expertise in data models, water infrastructure models, and interoperability. The Data Integration Steering Committee will work with the Center's Task Leaders to ensure that the EPANET and SWMM community viewpoints are integrated into the developing data and interoperability standards. We will identify relevant OGC standards that cross to elements within EPANET and SWMM and provide a mapping between an item from the standard and the element from the model. This enables crosswalks between models and data, similar to what has been done between the U.S. National Hydrography Data Set and the Canadian National Hydro Network through the OGC (Yu and Di, 2014). Working with city and industry stakeholders, we will look to new standards that are needed for the interoperability between data and models. For example, the PipelineML working group of OGC has principally focused on the needs of the oil industry. However, there are significant cross-overs to water distribution and stormwater piping that can be readily included. The Center will enable the Application Programming Interface (API) and data standards that allow industry to readily build user and analysis interface products that meet the needs of industry, engineers, and cities while using the reliable, proven computational core of EPANET and SWMM.

7 Contributions to Innovation in Outreach and Support

The Model Portal is an innovative adaption of existing technologies to provide a new collaboration and communication Center for the SWMM and EPANET communities. The open source *Journal of Water Infrastructure Modeling* is an innovative approach to using the "publish or perish" syndrome to assist in modeling professionalism by encouraging the submission of model codes, documentation, and test cases for publication. Our Business Plan relies on sound and proven approaches for establishing a sustainable Center. The integration with Building Information Modeling and the Open Geospatial Consortium is innovative in that these areas will allow new automated data sources for easier creation of EPANET and SWMM models.

8 Contributions to Sustainability

Sustainability of the Center related to Outreach and Support

The Business Plan is the bedrock for the long-term sustainability of the Center. We have confidence that our approach will provide a long term Center with self-sustaining outreach, support and code maintenance, and will provide a hub for coordination of externally-funded research projects.

Sustainability of the Models related to Outreach and Support

The Model Portal, crowd-sourced coding, and the committee/panel system (Section 10 Administrative Unit, pg 64) will ensure that the models can be sustained with community interest and without continual interjection of EPA funds.

Water Infrastructure for Sustainability related to Outreach and Support

SWMM and EPANET models are, at their most basic level, tools that can be used to assess sustainability implications of infrastructure decisions. However, to make these models practical tool, they need automated connections to Building Information Modeling, Civil Information Modeling, and land surface models. Our connections to the OGC and BIM worlds are the first step in making these models more practical "what if" tools that will (someday) be able to be run with automated data connections across a Smart City.

9 Expected Results, Benefits, Outputs and Outcomes for Outreach and Support

The **expected results** are: (i) the establishment of a Center that provides a sustainable hub for innovation, training, outreach, community engagement and support without continual injections of EPA funds; (ii) a professional operation that has the confidence of industry, government, and academia; and (iii) a systematic approach to crowd-sourced code development with Center oversight and stakeholder control by Model Expert Panels.

The **outputs** are: (i) a Model Portal with a Community Communication system, a Case Library and a Document Library; (ii) workshops, training, and support for the models; (iii) the new Journal of Water Infrastructure Modeling (JWIM) focused on publishing code, documentation, and test cases, (iv) sematic mapping between EPANET and SWMM data structures and data structures in BIM/CIM models and OGC standards; and (v) a sustainable business structure for the Center.

The **benefits** are: (i) the model versioning, bugfixes, and a centralized system for maintaining model code will simplify the task of programmers, users and model maintenance; (ii) an engaged community of users and modelers using crowd-sourced programming will be able to innovate with SWMM and EPANET codes; (iii) providing a publication (JWIM) focused on code will encourage programmers and users to more fully document their model adaptions and test cases; (iv) the collaboration with Building Infrastructure Modeling and the Open Geospatial Consortium will lay the foundations for automated data input to EPANET and SWMM from Smart City advances, and (v) the Center will be able to function for the life of the EPANET and SWMM codes as a hub for training, support, and model maintenance.

The **outcome** is a vibrant community-oriented Center that keeps EPANET and SWMM moving forward in the 21st Century.

10 General Project Information for Outreach and Support

10.1 Unique capabilities of the project team

We are in an outstanding position to create an effective and long-term sustainable outreach and support through the combined teamwork of UT, UWRI, BYU, and TTU. At the foundational level: Co-PI Ames at BYU will build the Model Portal and Co-PI Cleveland at TTU will organize and test the the baseline source code, executables, and model documents prior to distribution. UWRI has an enviable record of delivering high quality training and effective model solutions at minimum cost. The Institute was designed from the ground up with low overheads in mind, and does not support a large associated internal infrastructure. As such, focusing the professional activity of training and support on the UWRI side of the balance sheet lends itself to a successful launch of this aspect of the new Center. UT provides the Center's operational and administrative hub with long-term archiving and an outstanding record of accomplishment and value delivered in R&D. As a center of model development directly related to the requirements of the present proposal, it is appropriate that the Center for Research in Water Resources at UT's

JJ Pickle Research Center is the hub for the research elements of this project. In terms of current research, UT has an excellent record working on research related to modern engines of the type that will be needed in this project.

Pivotal in our Center team is Co-PI Rowney, who has extensive experience working with both academia and industry in water infrastructure modeling. Dr. Rowney will be the Center Associate Director (as a UT Research Affiliate) and will take charge of the Business Plan, which would otherwise difficult for academic-oriented researchers to implement. His experience in industry and practical business management including experience in enterprises over a wide range of sizes and scales of operation, will make our business development plan a demonstrable success – which we believe is a key strength of our team.

The close proximity of TTU to UT is an asset for team meeting and close cooperation between code development and novel research. The more remote location of BYU is immaterial given the strong focus of Co-PI Ames on community and Model Portal Development. Indeed, the locations of the team members, physically including every time zone in the nation, will be an asset when responses to local user needs is necessary, and experience among the team members, who have worked together for years on comparable projects, is that location does not impair team performance in a program such as the one at hand.

We have confidence that our Model Portal will be a successful and powerful addition to the SWMM and EPANET community building due to the experience of co-PI Ames in managing the releases of various open source software packages including MapWindow GIS (Ames et al. 2008) and HydroDesktop (Ames et al. 2012). The software code repository, code versioning system, and release management system of HydroDesktop are available online at http://hydrodesktop.codeplex.com.

There is another element of the project team that bears consideration, given the importance of the community outreach elements of the program. The group displays a very strong and long term commitment to the community already. Team members include:

- Past Chair, Vice Chair and Secretaries of the Urban Water Resources Research Council of the Environmental and Water Resources Institute of ASCE.
- Numerous long term members of the Urban Water Resources Research Council of the Environmental and Water Resources Institute of ASCE.
- Board Member and Chair of the Technical EXCOM, Environmental and Water Resources Institute of ASCE.
- Project Director (and all code writing) for the recent Water Environment Research Foundation Framework project
- General Chair of the World Environmental and Water Resources Congress
- Presenters of numerous papers and documents attested to in the resumes included with this project.
- Interaction with, and an understanding of, the needs of vendors and developers.

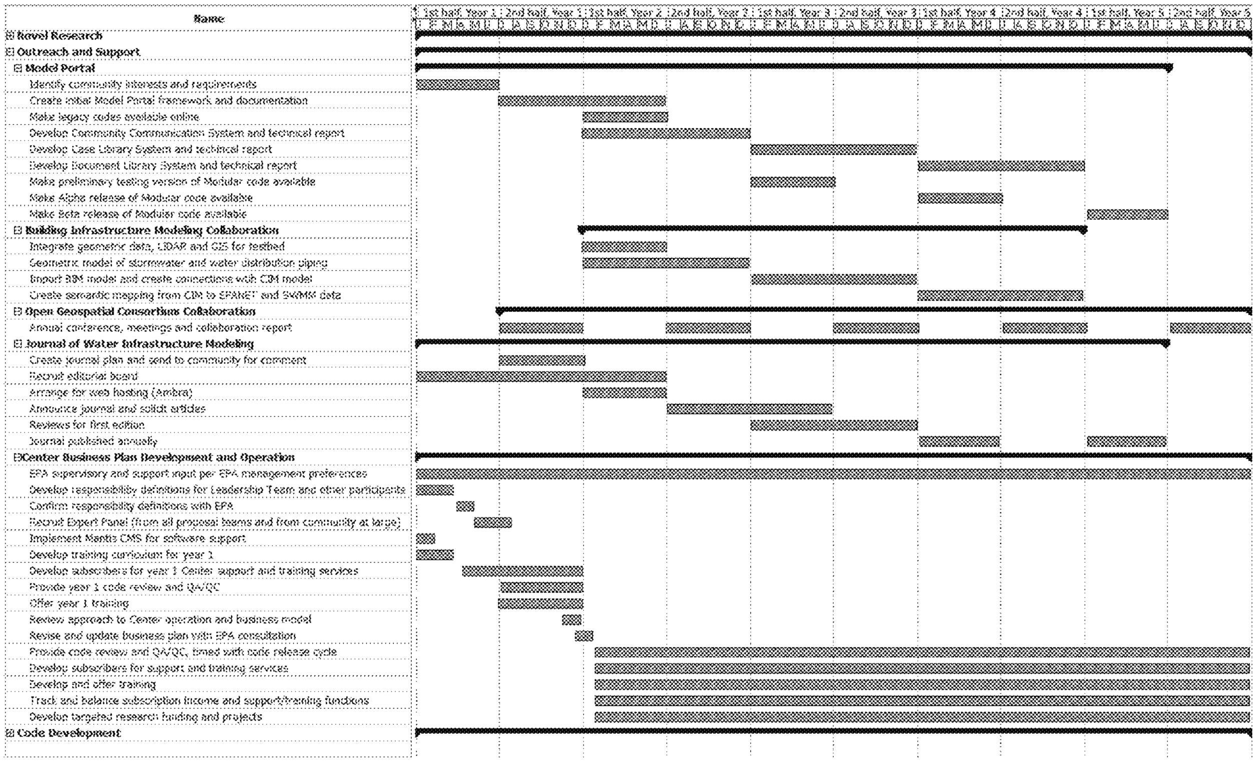
This is a group that clearly has an exceptionally strong network in the very community to be targeted by this project. We believe this is a material success factor that will prove to be a major asset in the community outreach aspects of this project.

10.2 Facilities and management

Facilities are discussed in detail in Section 6C Novel Research (pg 40). Management is discussed in detail in Section 7 Quality Management Plan (pg 55), Section 9 Data Plan (pg 61), and Section 10 Administrative Unit (pg 64)

10.3 Schedule

An assessment of resource loading, logical sequence and program requirements was carried out. Based on that assessment, a time schedule was developed. The GANNT below provides an outline of a program that delivers the items discussed above.



Note that the collapsed time lines (Novel Research and Code Development) are provided in their respective sections.

Section 6B: Code Development (Subproject 2)

This project will provide:

- Archived and maintained baseline version of existing EPANET and SWMM.
- New modularized versions of EPANET and SWMM
- A new sub-segmented Eulerian Transport algorithm for EPANET to enable more complex biofilm, security, sensors, real-time modeling and monitoring expansions in the future.

1 Motivation, Goals and Objectives

The motivation for this subproject is to meet the needs of the community for SWMM and EPANET models that are modularized, easily maintained, version-controlled, and readily adaptable for future expansions.

Our primary goal is to rework the internal structure of EPANET and SWMM to make it easier to understand, simpler to modify, easier to test and validate, and more robust for the community of users and programmers. In this subproject we accomplish this goal while maintaining the underlying functioning of the code. Note that in Section 6C Novel Research (pg 40), we address changes to the underlying code algorithms for development of a common numerical solver.

Our secondary goal is to implant handles to facilitate future model expansion. Vital future expansions are: vectorized[1] code options to improve speed in CPU computing engines; parallelized code options to facilitate use of GPU computing engines; and documenting taxonomical similarities of distribution systems (EPANET) and

Objectives

1. Archive and make available on the Model Portal the legacy EPANET and SWMM codes as baseline code/models.
2. Create a component model environment for modularized SWMM.
3. Create a component model environment for modularized EPANET.
4. Create cross-connections and commonalities between the two component model for an integrated model environment.
5. Create an Eulerian Transport module for EPANET that supports advanced biofilm modeling.

[1] Here we mean "classical" vectorization enhancements – unrolling loops, inversion of constants and multiplication in lieu of division, arithmetic operations on entire arrays at once, and similar subtle speed-up coding.

collection systems (SWMM) to create a consistent representation for simulating either physical domain, or possibly a combined domain.

Detailed explanations of our motivations and background for the of modular and integrated component models are provided in §4 below.

2 General Approach and Activities

The first subproject phase works with the existing structure of EPANET and SWMM, providing a baseline for ongoing work by the community and for near-term advances in the models. A set of benchmark tests will be created whose primary purpose is to establish the "observed behavior" of the models under various simulation conditions. These models, along with these benchmark tests will be documented, made available, and supported through the Model Portal (Section 6A Community Outreach, pg 10).

The second subproject phase is a deconstruction of EPANET and SWMM5 into component modules (called *environments*, in keeping with common software nomenclature) so that extensions can be added and individual modules can separately tested, upgraded, and maintained. This avoids requiring systemic testing of the entire program with every new feature or bugfix. Here we distinguish between the present EPANET and SWMM5 software subroutine modules – which require monolithic code compilation – and independent modules that only have data transfer through the module interface and can be tested/modified as independent entities.

The key to modularized deconstruction is inter-module interfaces (and protocols) that facilitate data transfer among the environments. Furthermore these interfaces will serve as the handles for future enhancement and as entry/exit points for value-added vendors to access the codes without breaking the models apart. Component modules can be evaluated independently using the

Tasks

1. Develop functioning, documented, and version-controlled releases of the latest EPANET and SWMM codes and model executables.
2. Deconstruct EPANET and SWMM 5 into self-organized component modules (SOCMs).
3. Create an Eulerian Transport module for EPANET for use in an advanced biofilm module and to improve capabilities for security, sensors and real-time monitoring.

Products and Outcomes

1. Final (Stable) Release EPANET (EN2)
2. Final (Stable) Release SWMM5
3. Initial Release Modular EPANET (EN3)
4. Initial Release Modular SWMM (SWMM6)
5. Initial Release Integrated SWMM-NET
6. Eulerian Transport Module for EPANET (EN2, EN3) with documentation.

Method of Manufactured Solutions (Oberkampt and Blottner, 1998; Roache, 1998,2002; Salari and Knupp, 2000; Knupp and Salari, 2010), which provides greater reliability as models are modified and tested.

The products and outcomes (see box above) will be made available on the Model Portal and will include: (i) source code, (ii) compilation instructions for the simulation engine and graphical interface engine targeted for Windows, Linux, and Mac OS architectures, and (iii) user manual. The user manual will be enhanced to include additional set-by-step use examples; i.e. not just how to populate input screens, but also the art of modeling; making assumptions, selecting details to omit and include, and similar such modeling decisions. A library of input files and narrative conceptualizations will be included that establish the "observed behavior" of the code base and comparisons to the base case for the Modular and Integrated codes. A Translator Component Module (§3.2.8) will include a separate user and technical manual to facilitate value-added vendors access to the model.

3 Task Details for Code Development

3.1 Task 1: Develop functioning, documented versions of the latest EPANET and SWMM codes and model executables.

3.1.1 *Construct a database of SWMM and EPANET case study models*

As a baseline for SWMM and EPANET in the Model Portal (see Section 6A: Community Outreach and Support, pg 10), we will develop a set of case studies for testing that simulate real and hypothetical systems. The case studies will be stored in a database that is organized in a similar fashion to the International BMP database. Existing models in use would be sought from the practicing community to populate the database. The final database will include descriptive reports, input files, and a set of output files that provide a reference for future comparisons.

3.1.2 *Construct the final (stable) release versions of EPANET and SWMM5*

These versions will not add new functionality, but will reflect most current code maintained by the EPA. These releases will be used to test the versioning, release, and issue management system of the Model Portal. Binary executables for Windows, Linux, and Mac OSX will be constructed and provided to the Model Portal. Compiling to all three common operating systems will prepare the team for the deconstruction activity by identifying confounding code elements, most likely in the interface components.

3.2 Task 2: Deconstruct EPANET and SWMM 5 into self-organized component modules (SOCMs)

Self-organized component modules (SOCMs) are code modules that share related context and can be modified/extended separately from the other modules in the code (within specified limits). The broad concept of self-organization (and self-repair) is an emergent strategy in building dependable hardware systems (Boesen et. al., 2011), however the concept is not only adaptable and especially appropriate at the architectural description language level (Okon and Asagba, 2013; Okon 2006; Hansson, et. al., 2004; Magge et al., 2002), it is often used to test the hardware strategies in software simulations. These SOCMs will enable current and future developers to develop extensions to these flagship models at the component level eliminating a need to rebuild the entire code as features (or entire SOCMs) are added. Further background details on SOCMs and code modularization will be found §4. The SOCMs (described in the following subsections) can be envisioned as an interlinking system, as shown in Figure 6B-1.

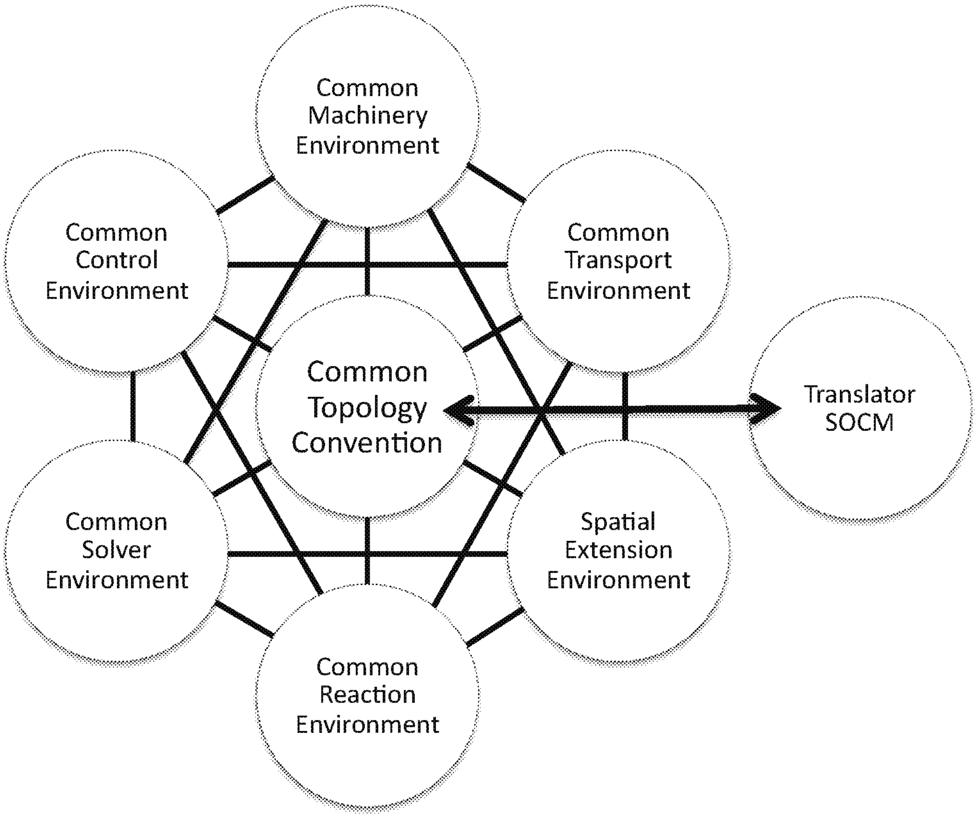


Figure 6B-1. Communication between component environments around a common topology convention. Each environment has methods for communicating with all other environments. The Translator SOCM is the interface between legacy EPANET/SWMM file formats and the modularized code.

3.2.1 Common Solver Environment (CSE):

The core of EPANET and SWMM are matrix solvers. We will create a single CSE for existing solvers (i.e. the sparse matrix EPANET, Picard iteration in SWMM), which will allow ready inclusion of other solvers can be used and become part of the modeling center. The CSE will allow programmers to readily access the data structures that require matrix solution and implement different solver algorithms without affecting the other modules. The CSE provides the framework that will be used in developing the Common Numerical Core (see Section 6C Novel Research, pg 40).

3.2.2 *Common Topology Convention (CTC)*

The CTC is aimed at establishing a fundamental element-naming convention so that piping and landscape network topologies are named, organized, and solved in a common structure regardless of the real-world network source (i.e. distribution or collection system network). The CTC will include common geo-referencing and spatial linking protocols, with linkages to GIS. The CTC would be user transparent – that is the program would handle internal naming of elements, and relate them to user-specified names (as with the existing system). However, developers will be able to apply the CTC conventions to maintain encapsulation features in discrete modules when developing new code for EPANET and SWMM. The CTC will enable the modeling tools to take advantage of known topologic structure to simplify programming adaptations and speed up code; i.e. existing modules using the CTC approach will automatically understand data in new modules or functions that use CTC.

3.2.3 *Common Machinery Environment (CME)*

The CME is a convention and set of modules that simulate the functions of machinery in either a distribution or collection system network. Pumps, turbines, valves, weirs, would be components of this environment. Structural BMPs (as opposed to conveyance element BMPs, see CTE below) will be handled as part of CME.

3.2.4 *Common Transport Environment (CTE)*

The CTE is a convention and set of modules that simulate the behavior of conveyance elements in a network. Pipes (both pressure and open flow), ditches, sewers, and such elements would be part of the CTE. Storage components, while not actually conveyance, will be contained in this environment because they are characterized by their geometry and inflow/outflow.

3.2.5 *Common Reaction Environment (CRE)*

The CRE is a convention and set of modules for biochemical reactions. The CRE is likely to substantially interface with the CTE and CME. The development of this environment will be closely tied to the development of the new biofilm algorithms (see Section 6C Novel Research, pg 40)

3.2.6 *Common Control Environment (CCE)*

The CCE is a convention and set of modules that simulate control actions on the network. CCE is where the other SOCMs are accessed when building an actual model and is the core of the SOCM interactions. Additionally the CCE modules could issue control instructions to the model (and by proxy to an actual system). The CCE is also where sensor inputs would be contained – the assumption is that sensing and control are intimate, so they should reside in the same environment.

3.2.7 *Spatial Extension Environment (SEE)*

A spatial extension environment is a set of modules that facilitate use of the existing link-node models into quasi 2D and 3D spatial environments. As an example SWMM can currently be configured to approximate 2D overland behavior (Cleveland and Botkins, 2008), although it seldom is done because there is a substantial investment in building the network to simulate 2D flows. However where appropriate, it is a meaningful exercise and far faster than migrating to true 2D and 3D modeling tools.

3.2.8 *Translator SOCM*

We will develop a translator SOCM that can convert legacy input files into the SOCM based modeling system and visa-versa. This activity not only maintains forward-compatibility but assures that value-added vendors can continue to access and support the models through data file manipulation by using the translator SOCM to communicate with the deconstructed models.

3.3 Task 3: Create an Eulerian Transport module for EPANET

The link-node flow solution and Lagrangian transport in EPANET does not resolve spatial gradients along pipes, which are necessary for both advanced biofilm modeling and for higher resolution in security, sensors and real-time monitoring. We will develop a sub-segmenting approach for Eulerian Transport computation that can be used with the existing and modularized EPANET. This module will be designed to be compatible with future extensions of EPANET to solution of the full time-dependent dynamic equations, which will be necessary for effective implementation of security, sensors, and real-time monitoring. The Eulerian Transport module sub-segment the flow computations of EPANET and compute scalar advection-diffusion-reaction equations along the pipe length. This will allow biofilms (Section 6C Novel Research, pg 40) to develop spatially along a pipe length.

Sub-tasks for Eulerian Transport module

- Task 1: Write a white paper on generalized Eulerian transport algorithms for network problems solved efficiently multi-core and GPU processor workstations.
- Task 2: Commission external review of Eulerian transport algorithm white paper.
- Task 3: Hold a community workshop to evaluate the proposed Eulerian transport algorithms.
- Task 4: Commission either external or internal expert on transport algorithms to write or an Eulerian transport solver and develop a segmented transport algorithm and data structure compatible with both EPANET and SWMM. This solver will supersede the Lagrangian transport algorithm in EPANET.
- Task 5: Create and conduct a validation program (either internal or external) for the Eulerian transport algorithm.
- Task 6: Implement the Eulerian transport within the modularized SWMM and EPANET models and conduct final testing.

Products and Outcomes for Eulerian Transport module

- White paper on Eulerian transport algorithms
- External review report and community-recommended Eulerian transport algorithms.
- Open-source code and documentation (in-code commenting) for Eulerian transport.
- Technical Report (User and Programmer's Guide) for Eulerian transport algorithm.
- Technical Report on validation and testing of Eulerian transport algorithms.
- Technical Report (User Guide) on implementation of Eulerian transport in EPANET.

4 Background and justification for Modularization

4.1 Why rewrite what works?

Although EPANET and SWMM5 are robust and relatively bug-free, they need to be adapted to meet future needs, for example:

- New capabilities are needed (e.g. improved Green Infrastructure, Biofilm Kinetics),
- Advances in computer architectures require porting the code to new systems (e.g. GPU processors).
- New types of urban water infrastructure data need to be integrated (e.g. Building Information Models, PipelineML).

Because the present versions of EPANET and SWMM were designed in the late 1990s, they use a classic coding approach with a monolithic collection of subroutines that share common data structures. This approach was appropriate based on software practices at the time with highly constrained computer memory; but modern desktop computers have more than enough memory to handle modularized code, and software practices have evolved to allows greater code adaptability. There is a compelling need to restructure the EPANET and SWMM codes to enable simpler modifications, maintenance, and architecture stability for an extended life-cycle. This is particularly true as the code is moved from EPA code management into a crowd-sourced code management system (see this proposal Section 6A: Community Outreach and Support).

4.2 Why a legacy code project?

We believe it is critical to archive make available the legacy EPANET and SWMM codes as baseline code/models (§3.1 above). This effort provides a code baseline for comparison to future models to assure that observational behavior of the models is maintained. These models will continue to be used, modified, and maintained in the versioning control system of our Model Portal until eventually phased-out by the new modularized versions. In our long-term-support (LTS) model we will continue bugfixes and support of the legacy codes for 5 years – and maintain these codes in the Model Portal in for indefinite time beyond for archival use. However, beyond 5 years the codes will no longer subject to Center oversight of community-contributed bug fixes[2] and no further official releases based on the legacy codes will be made.

[2] Analogous to the CentOS Linux distribution where the current version is CentOS8; earlier versions can still be downloaded and will run.

4.3 Why use Component Environments?

Both EPANET and SWMM 5.0 are C++ codes use subroutine modules that must be compiled and tested as a monolithic program. The program architecture is established, hence update, repair, and maintenance require identifying the code module involved, making changes, compiling the entire program, and then testing the new program to be sure the activity did not break anything or substantially degrade the program architecture. The Component Environment (§3.2 above) changes this paradigm so that individual modules can be modified and tested separately within a consistently defined "environment." These Component Environments can be visualized as collections of separate modules (like smart phone applications) that interact with data and with each other. The Component Environment concept is a way group modules that share similar characteristics and nomenclature. Within an environment the set of modules may be quite large (not unlike a conventional C++ program). Our approach will simplify future expansions of EPANET and SWMM and draw the codes closer together, which will make maintaining the programmer base more practical. The Component Environments will still treat the distribution system and collection system as separate domains, but will leverage commonality to reduce the complexity of the code base. New programmers can more readily grasp the intention and functioning of different modules in a Component Environment without having to separately investigate each and every module in the environment or in the code.

When one environment needs another, the dependencies will be resolved during runtime. This process will function similarly to a Linux package manager that can detect a missing package, search a repository, find the package, download and install the package, halts and restart the process, and then continue execution. This approach to *just-in-time* and *just-what-is-necessary* will allow for efficiencies in model execution, computation speed, and long-term maintenance. The *just-what-is-necessary* component provides a way to evaluate system utility for long-term maintenance. Modules that are rarely used can be deprecated or absorbed into more commonly used modules during code maintenance.

4.4 Refactoring/deconstructing the codes to produce modules

"Refactoring" is the software engineering term for modifying existing code to maintain outward functional behavior, but improve internal behaviors for maintainability, speed, and/or robustness (Fowler, et. al., 1999). Considering the EPANET and SWMM codes to each be a monolithic black box, we will be refactoring these codes to maintain the external behavior. Figure 6B-2 depicts items that are requisite for refactoring success, however, more than simple refactoring (to achieve the "quick wins"), we are going to be entirely deconstructing the codes into independent modules (to achieve a high degree of granular "divide and conqueror"). In the future, refactoring to improve performance will be able to be accomplished on a module-by-module basis. Building in "quality" is the reason for both the legacy project (to compare to an already mature model) and the MMS activity. Figure 6B-2 may seem to trivialize the exercise with it slogans, however the deconstruction process requires careful attention to detail, keeping the end goals in mind, and having a clear strategy for defining quality.

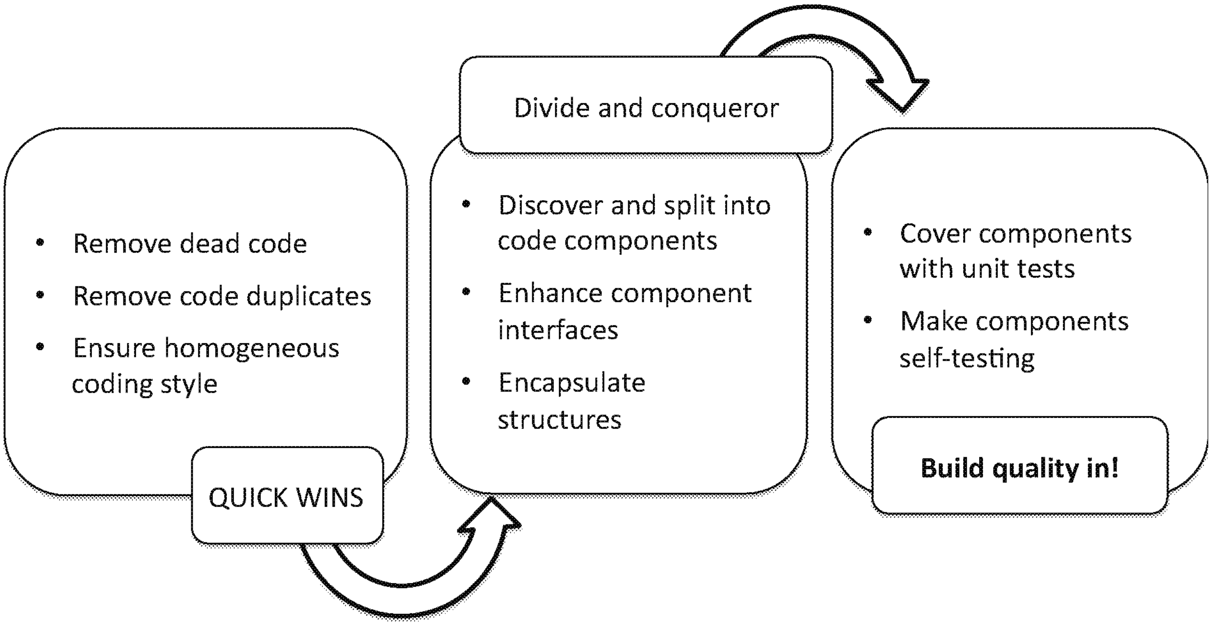


Figure 6B-2. Refactoring success model

Deconstructing these codes provides multiple benefits including:

1. Deconstruction will help avoid long-term architecture (program structure) degradation, greatly enhancing maintenance and expansion capabilities.
2. Deconstruction will identify locations in the code where improved computation methods can enhance the speed and accuracy of the models.
3. We will be able to develop code security features to ensure that illicit code cannot be inserted into modules; that is, with module functionality limited to specific tasks and inputs/outputs, we will be able to include automated checksum features that can be used to detect and localize any module changes from the release version.

The existing subroutine modularity of the codes will be leveraged in the deconstruction effort. Note that the refactored Component Environments will be a fundamentally different computational architecture that current EPANET and SWMM5, but will retain the same observed behavior and outward data file structure.

Modularization will make it possible to eventually combine EPANET and SWMM for simpler code maintenance – i.e. the transport through networks (whether full pipe, sewer, or open channel) is governed by the 1D unsteady momentum and continuity equations, so a single flow solver could be deployed for both models (see Section 6C Novel Research, pg 40).

4.5 Modularization for crowd-sourced coding

Deconstruction will create a set of independently compiled, tested, and released domain modules (i.e. self-organized component modules, or SOCM). Updates can be made to a single module without affecting other modules, which supports and encourages model improvements and testing in small pieces. With the existing paradigm, users needing a new feature must either wait for EPA to code, test, and release a new version of a model, or make a new version of the code that includes their feature – this approach results in the proliferation of codes with different capabilities and incompatibilities. With the modularized format, a user only needs to change the module that controls the particular feature, e.g. adding a new pump behavior to the Common Machinery Environment. By maintaining the modified module in GitHub on the Model Portal, other uses will have access to either the modified module or the original module. As other users develop their own customizations, a user is free to choose from the available modules that suit his/her purpose with the confidence that all the modules will work together.[3]

5 Integration with other subprojects

Code development is tightly integrated with the Community Outreach through the Model Portal, which will be used to make the code, executables and documentation available to the public. The research team developing the modularized code will work closely with the research team in Novel Research so that new developments will function in the modularized environment.

Ongoing development of modules will be in conjunction with the Model Expert Panels and Stakeholder Panels to ensure the community is involved in decisions affecting the code future (Section 7 Quality Management Plan, pg 55).

6 Contributions to Innovation

This Code Development subproject prepares the groundwork for future innovation. The key problems for innovating with the existing EPANET and SWMM codes is that a programmer must be familiar with almost the entire structure of the code before changes can be made. This is not a criticism of these models, but is simply where the state-of-the-art in software was when the latest versions were being written 15 years ago. By modularizing the code with the latest approaches in software design, we will provide a stable platform for innovation in these models over the next 20 years. Based on history, it does seem likely that new developments in computers, software and will require model rewrites on a bi-decadal basis, however this cannot be a reason to delay the proposed modularization program. EPANET and SWMM codes must be modularized so that they can be readily adapted to hyperthreading, GPU processing, and parallel core CPU systems, else they will likely be eclipsed by other models over which the Center and the open-source community will have little control.

---

[3] The Scratch (Maloney et. al. 2009) programming language is a good example of a highly modularized computing environment. The language is intended for "kids" but is a fully capable programming environment that can be used to run simulations, build animations, and multi-media presentations. It uses the metaphor of visual programming – not unlike drawing network components then linking them. A user can program a component in to interact with the rest of the environment – even without knowledge of how the other parts work, only that the other parts receive and send particular input.

7 Contributions to Sustainability

Sustainability of the Center

Modularization of the codes will allow the Center to work more readily and inexpensively with industry in development of new algorithms for such things as BMPs, sensors, real-time monitoring, or water quality. Integrating new algorithms into the models will be simpler the testing process requires only testing the changed/new module and testing the interactions between modules. Furthermore, modularization will allow the Center to work with vendors who would like to develop/sell proprietary modules that work with the EPANET/SWMM computational engines. The public/private partnership will be enhanced by modularization and create a more vibrant, sustainable programming community and hence a more sustainable Center.

Sustainability of the Models

Sustainability for the model is achieved by our "crowd-sourced" community coding approach, which reduces our reliance on a single person or small group of programmers to maintain the model. The decomposition into modules enables groups of users and developers to focus and specialize on improving portions of the model that are critical to individual project needs. The Center will maintain testing conventions through the Model Portal to ensure that additions do not break existing code.

Water Infrastructure for Sustainability

The modularization of the codes will allow future development of sustainability modules that work directly with EPANET and SWMM. Questions in sustainability typically require creating "what if" scenarios and comparing results to optimize a design. Presently, sustainability computations require setting up separate input files, running multiple models, and analyzing multiple model results. However, with a modular model system it will be possible to build a sustainability module that creates a range of model inputs based on the user selecting baseline, and two typical limit cases. For example, for implementation of BMPs in a new housing development, a user might specify a baseline set of BMP distributions based on engineering judgment and then use zero BMPs and maximum BMPs as limiting cases. A sustainability module could then automatically create a series of Monte-Carlo simulations with different BMP distributions and provide analysis of results. Although it is also possible to build a similar capabilities around non-modularized models using a "wrapper" (e.g. Hou and Hodges, 2014; Yang et. al., 1996; Joshi, 2000) the task is simplified and made more maintainable/adaptable by having modules that are directly addressed.

8 Expected Results, Benefits, Outputs and Outcomes

The **expected result** of this project is the successful creation of a modularized set of codes that are made available to the community as open-source products on the Model Portal.

The specific **outputs** (made available in Model Portal) will be:

1) a set of final (stable) release legacy source codes and executables of EPANET and SWMM for public use and archiving;
2) a database of test cases;
3) user/programmer documentation that includes user self-training in modeling.
4) efficient, modular set of codes that maximize model maintainability.

The **benefits** of this subproject are:

1) the maintainable, modular codes will eliminate the need to rebuild and test the entire model code for small change, which will reduce the costs of innovation.
2) the modular codes will be more accessible to a broader group of programmers, as a specialist in a particular field (e.g. biofilms) will not need to understand the entire code to implement new algorithms;
3) the modular codes provide an expandable coding concept will allow ready extension of the codes to innovative uses and new modules;
4) the database of baseline model behavior provides the foundation for quality control checks of future code changes; i.e. future codes can be compared directly to the baseline legacy codes outputs for exactly the same input data.

The long-term **outcome** will be providing a solid software and computational framework for EPANET and SWMM for the next 15-20 years of service.

9 General Project Information

9.1 The coding team

A consideration for the EPA in deciding where to place the National Center in Sustainable Water Infrastructure Modeling will be their confidence the coding team that will be involved. The key coding team for this project will be PIs Cleveland, Rowney and Hodges. All have decades of experience in writing clean and comprehensible code for water resource modeling, and all are committed to actively working with the code as well as closely supervising students and post-doctoral scientists. All model code will be read, run, and commented by multiple people. Co-PI Cleveland will work as a Research Affiliate at the Center for Research in Water Resources at UT Austin during the summers. Coding will be a team effort, with a focus on QA/QC, testing, commenting and documenting.

During the pre-proposal of this project, we consulted with and considered bringing in computer science co-PIs. However, we came to the conclusions that (1) our team is up-to-date on software architecture and coding practices, and (2) the software engineering profession is still lagging in their understanding of effectively implementing computational models (i.e. they are too focused on “point and click” consumer applications and Big Data extraction tools at the expense of APIs targeted to the water resources and engineering industry). Furthermore, to develop a vibrant water resources programming community for crowd-sourced coding, it is vital that the code be written by practiced engineers with insight and thought processes likely to be used by the engineering programmers who will be modifying and adding to the code in the future.

9.2 The Method of Manufactured Solutions for code testing

A key part of quality control for our coding team will be implementation of the Method of Manufactured Solutions (MMS) (Roache 2002, Knupp and Salari, 2010). This approach to software testing was developed because of the difficulty in testing the interactions of nonlinearities in 3D hydrodynamic models, but is applicable to any model as well as the individual modules developed in this project. The fundamental idea of MMS is easiest to illustrate heuristically with matrix algebra. Given a matrix equation of the form $\mathbf{Ax} = \mathbf{b}$ where $\mathbf{A}$ is a nonlinear matrix, $\mathbf{b}$ is the known source, and $\mathbf{x}$ is unknown vector. The desired code output is $\mathbf{x} = \mathbf{A}^{-1}\mathbf{b}$. We are unlikely to have a known (non-trivial) solution for any sufficiently complicated $\mathbf{A}$ that truly tests a solver. However, we can *choose* (i.e. manufacture) a set of known values, say $\mathbf{y}$, from which we can compute $\mathbf{c} = \mathbf{Ay}$ in a straightforward manner. It follows that we can then replace the right-hand known $\mathbf{b}$ with $\mathbf{c}$ so that our code solves $\mathbf{x} = \mathbf{A}^{-1}\mathbf{c}$, which should produce $\mathbf{x} = \mathbf{y}$, allowing us to exactly evaluate the code error based on its ability to produce the manufactured solution. Note that $\mathbf{y}$ is not a solution of $\mathbf{Ax} = \mathbf{b}$, but that is immaterial to whether the solver is working. The full method is somewhat more complicated, but the above provides the general idea. MMS can be extended to most modules in the following fashion: manufacture a desired “output” and reverse engineer the inputs that should provide that output, then test that the module applied to the reverse engineered input provides the same result as the manufactured solution. An important point in applying this technique is that the production of the reverse engineered input cannot depend on the module code itself; using the example above, the computation of $\mathbf{Ay}$ must be simpler than the computation of $\mathbf{A}^{-1}\mathbf{b}$ and must not rely on computation of $\mathbf{A}^{-1}$. This requirement will generally be the case for the critical numerical computational modules where MMS will be vital to detect logic flaws.

9.3 Facilities and Management

Computational facilities are described in Section 6D Novel Research (pg 40). Use of GitHub with check-out/check-in and versioning essentially virtualizes the code development “facilities” in the conventional sense. The code development team will however maintain independent target “machines” for pre-deployment testing in the three common operating systems (Windows, Linux, Mac) and for building and testing package installers. Each of the code team PIs has practical experience in building servers in multiple operating systems (Windows, Linux, and Mac OS) and in parallel machine building.

Managing of code development will be will follow a seven-phase methodology common in control software development.[4]

1) Source code management will use GitHub-type structure with rigorous versioning control and authenticated check-out/check-in policies.
2) Code reuse is assured in the modular deconstruction and for all practical purposes the SOCM environments are the analogs of project libraries.
3) Requirements Management is the purpose of the deconstruction guidelines in year 1 with the follow-up in year 2 as well as the purpose of the legacy activity. The requirement that the observable function of the two models not degrade is paramount in this phase.
4) Architecture and Design will be a major effort in years 2 and 3, essentially the deconstruction sets up the architecture, however we will employ package manager software (e.g. Homebrew) to track, update, and replicate architecture as it evolves. The value of this phase is to architect the code for future functionality, scalability, and modularity.
5) Debugging and Peer review using tracing tools will allow us to measure and demonstrate the quality of the code modules as well as detect common problems like spelling errors and memory leaks.
6) Testing and Execution Profiling. Using MMS to validate the codes along with alpha- and beta- test protocols we will be able to create and automate testing for future developers and verify the functional correctness of the code against requirements (i.e. same observable performance as the legacy codes)
7) Deployment. Unstable and stable (tested) versions will be deployed through the model portal with appropriate notes, installers, package managers and example files.

These seven phases, while presented sequentially are somewhat cyclic. Five are envisioned as contained in the main management nexus, which is the versioning system. Figure 6B-3 is a diagram of how these seven phases are envisioned as interacting. The source code and code reuse elements are entirely contained in the versioning system which is depicted by the dashed box – authenticated developers would be able to check-in changes, although all would be able to view elements within the versioning system. The requirements are envisioned as a stub off the code development cycle and would be more of a diary-like document; initially it is a technical report, but is allowed to adapt with time as deconstruction identifies successful changes and pitfalls. Architecture design, debugging, and testing are all envisioned as interacting with each other and with the code-reuse element. These activities are shown as partially shared outside of the versioning system to capture critique from the development and user community. Deployment is also envisioned as a stub off the development cycle. As described in the Model Portal subproject we will likely use a GitHub-type sharing model and some kind of concurrent

[4] Control software is high consequence code for running things like automobiles, railroads, aerial vehicles, water SCADA systems (autonomous mode), and other such things controlled by software where the item must be able to revert to some kind of fail-safe condition upon software or communication failure. A good example is software on-board remote piloted vehicles – if the vehicle loses connection with the controller the fail safe is to hover and attempt to reconnect and upon failing that execute an immediate autonomous landing. Other fail-safe conditions may be programmed depending on the operating environment.

versioning system (e.g. CVS, but others are available and useable by the team) to accomplish the actual mechanics depicted in the figure..

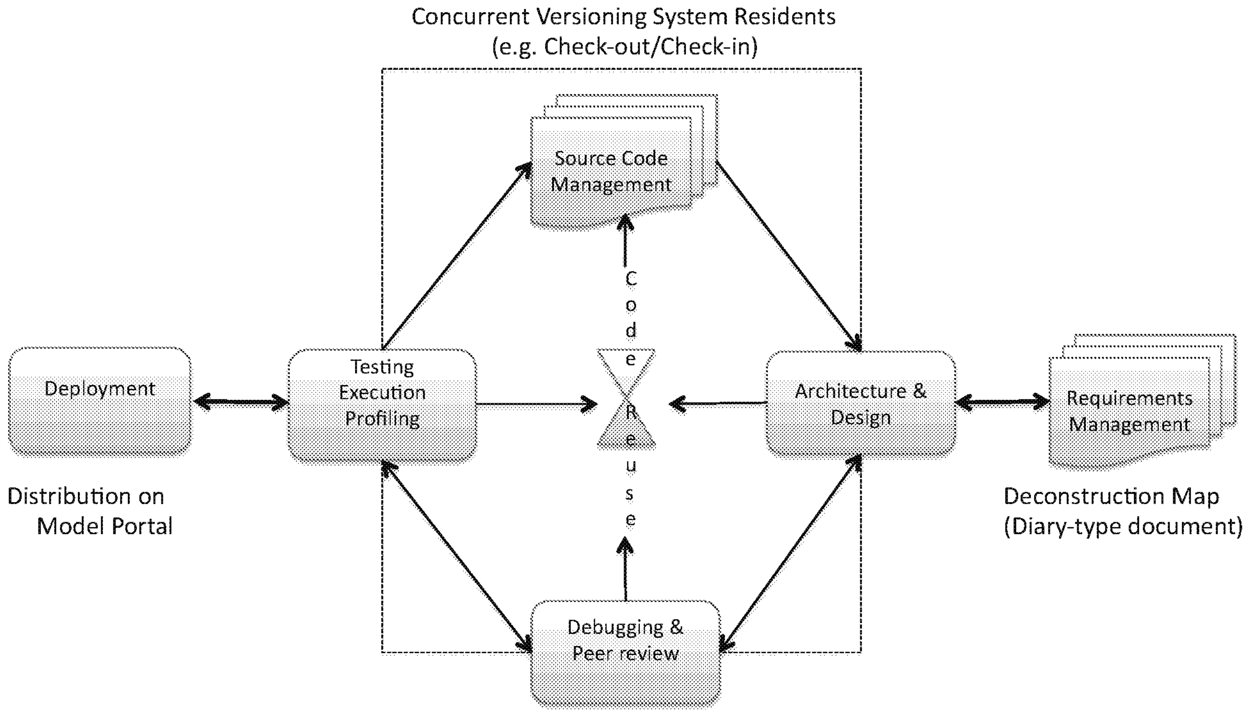
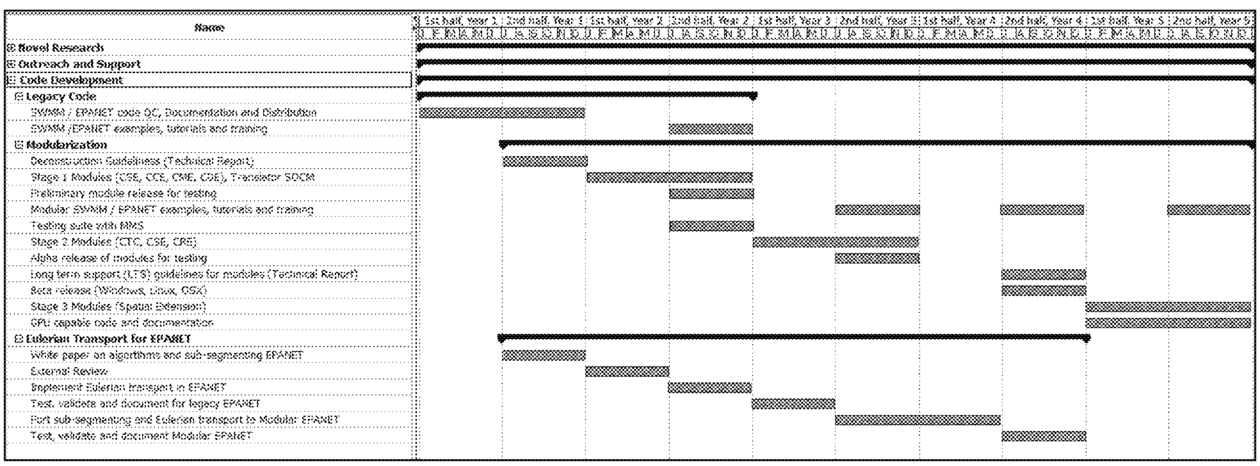


Figure 6B-3 Code Management Map. Work proceeds from defining requirements (on right) to feedbacks within the concurrent versioning system.

9.4 Schedule

An assessment of resource loading, logical sequence and program requirements was carried out. Based on that assessment, a time schedule was developed. The GANNT below provides an outline of a program that delivers the items discussed above.



Note that the collapsed time lines (Novel Research and Outreach and Support) are provided in their respective sections.

ED_002522A_00000271-00042

Section 6C: Novel Research (Subproject 3)

This project will provide:

- New adaptable and generic Green Infrastructure algorithms for SWMM.
- New Biofilm capabilities for EPANET.
- New numerical solution approach that takes a quantum leap, enabling response times fast enough for practical use when solving massive networks.
- New plan for implementation options for security, real-time monitoring, sensors and control in EPANET and SWMM.

1 Motivation, Goals and Objectives

Our motivation is to meet the needs of the user community for fast solutions by expanding SWMM and EPANET capabilities to address new challenges in water infrastructure modeling. Our subproject goals are to create the framework for innovation in SWMM and EPANET and embark on a consistent, staged approach to adding, evaluating, and documenting new features. Our long-term and 5-year objectives are outlined in the boxes at right and on the next page.

In conjunction with subprojects for Community Outreach/Support and Code Development (Sections 6A and 6B, respectively), we will build the Center personnel and administrative infrastructure to support novel research and code improvement across the community. The long-term objectives of the Center are to add improvements to SWMM and EPANET.

Unfortunately, all these objectives cannot be achieved with the Center's 5-year budget. We have chosen a subset for our near-term objectives that fit the planned scope. Our business goal is to develop funding streams that can help address the long-term objectives above that cannot be directly addressed at the

Long-term Research Objectives

1. Maintain model code that supports innovation.
2. Alternative faster numerical solvers that provide higher computational speeds and takes advantage of the latest generation of desktop computing (multi-threading and GPU processors).
3. New capabilities for SWMM in Green Infrastructure.
4. New capabilities for EPANET in Biofilms.
5. Real-time monitoring, sensors, and control with an emphasis on security issues for both EPANET and SWMM.
6. Integration of new system sensor technologies for both EPANET and SWMM.
7. Adaption of EPANET for multi-story buildings with integration to Building Information Modeling systems.
8. Integration of SWMM and EPANET with developing data standards of the Open Geospatial Consortium (OGC).

Achievable 5-Year Objectives for Novel Research

1. New model code that supports innovation.
2. Faster numerical solvers with higher computational speeds for desktop GPU processors
3. New capabilities for SWMM in Green Infrastructure
4. New capabilities for EPANET in Biofilms.
5. Preliminary studies of implementation approaches for security, real-time monitoring, and system sensor technology.
6. Development of data transfer from Building Information Modeling systems to EPANET as a precursor to multistory building capabilities.
7. Engaging in the OGC processes to have the EPANET and SWMM point-of-view represented as data standards are developed.

present time (Section 6A: Community Outreach and Support, pg 10). Note that the Center plans to further discuss the Novel Research objectives with both the EPA and the broader community, and we are open to changing our research emphasis for the 5-year EPA funding.

In the Achievable 5-Year Objectives, the development of new model code to support innovation (Objective 1) is described in Section 6B Code Development (pg 25), so it will not be further discussed in this subproject. Similarly, the development of the data transfer from the Building Information Modeling world (Objective 6) and engaging the OGC data standards process (Objective 7) are under the heading of Community Outreach and are discussed in Section 6A Community Outreach and Support (pg 10). We believe that by engaging in outreach in these areas, we can develop future funding to develop the Novel Research that will make it possible to meet the long-term objectives.

2 General Approach and Activities

The Center will focus and deliver improvements in four critical novel research areas over the initial five years of the Center:

1. Integration of Green Infrastructure components into SWMM (§3)
2. Integration of Biofilm modeling algorithms for EPANET (§4),
3. Improve the numerical solution speed for both models (§5),
4. Investigate the adaptable computational framework required for security, real-time monitoring, sensors and control (§6).

The first two improvements are low hanging fruit in that we already have an understanding of needs, requirements, and implementation equations. The third area will provide the greatest overall improvement in the models for the time invested. The fourth area is emerging as a critical need for the models, but we must have a better understanding of the needs and requirements of the community as well as potential implementation strategies before creating new code. The above improvements are detailed below; however, deliberations of the Center's Model Expert Panels (Section 10 Administrative Unit, pg 64) may alter our research focus to meet emergent needs of the community.

3 Green Infrastructure algorithms for SWMM

3.1 Overview

The goals of the Center's Green Infrastructure program are: (i) to increase the number of Green Infrastructure practices that can be represented in SWMM and allow future adaptation to new practices; (ii) to allow easy representation of effects of potential adoption of Green Infrastructure with wide distribution in the watershed. and (iii) to facilitate the connection between SWMM and decision support tools used for analyzing potential effects of Green Infrastructure. The associated tasks, products, and outcomes are listed in the accompanying boxes and are described in further detail in subsections below. To be succinct for the reader familiar with Green Infrastructure issues, details on the background, motivation and justifications for these tasks will be found in §3.5 below.

3.2 Task 1: An adaptable Green Infrastructure algorithm for SWMM

We will create a generic Green Infrastructure algorithm based on the existing bioretention system of infiltration, sedimentation, filtration, ion exchange, biological uptake, evapotranspiration and storage as shown in Figure 6C-1. Different components of Green Infrastructure can be modeled based on the bioretention system model with different compartments turned on/off and provided with different coefficients. For example, a green roof can be modeled as a bioretention system with a thin media layer and the underlying permeability set to zero. We will create adaptions of this single algorithm to represent the existing Green Infrastructure features in SWMM. Guidelines will be developed for applying, modifying, and

Tasks for Green Infrastructure

1. Create and adaptable Green Infrastructure algorithm for SWMM.
2. Create models for "lumping" distributed Green Infrastructure practices at watershed scale.
3. Create interface between SWMM and Decision Support Tools.

Products and Outcomes for Green Infrastructure

1. Adaptable Green Infrastructure module for SWMM (Task 1)
2. Technical Report (User Guide) for creating new Green Infrastructure components using the Adaptable Green Infrastructure module (Task 1)
3. Technical Report (User Guide) for creating lumped representation of distributed Green Infrastructure effects in SWMM (Task 2).
4. Module to provide number, size, and performance of Green Infrastructure components and other BMPs used in a SWMM model. (Task 3).
5. Technical Report (User Guide) for creating and using BMP/GI output from SWMM in either text file or through an API.

validating the algorithm for new Green Infrastructure features.

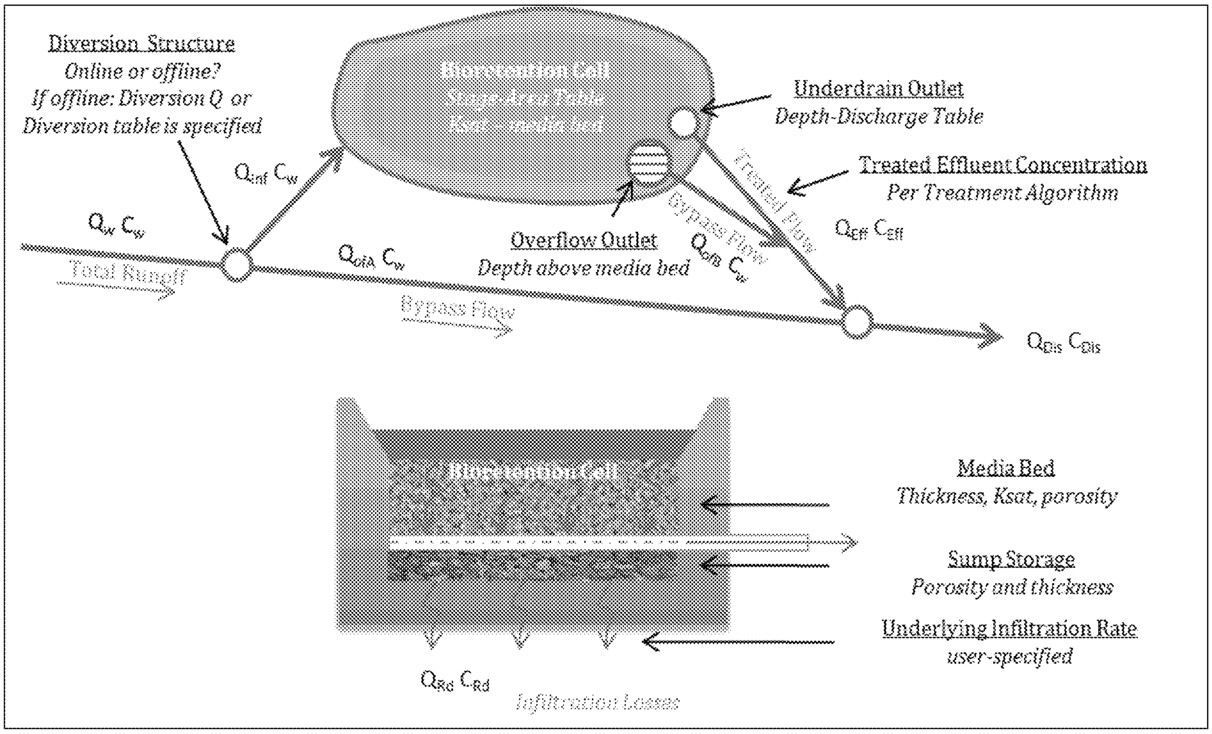


Figure 6C-1. Bioretention cell as the base model for Green Infrastructure in SWMM. The bioretention cell contains all the fundamental features of a generic Green Infrastructure component.

3.3 Task 2: Create models for "lumping" distributed Green Infrastructure practices at watershed scale.

The methods for lumping the effects of distributed Green Infrastructure practices at the watershed scale were previously proposed by co-PIs Barrett and Rowney (Barrett et al, 2012). Thus, in terms of our funding cycle for new research (Section 10 Administrative Unit, pg 64), we have already available a review of needs, requirements, and implementation equations for Green Infrastructure improvements, and can proceed directly to implementation.

We will implement the methods and evaluate their effectiveness by comparing their output to a test watershed where the Green Infrastructure practices are modeled explicitly. Using these results, we will recommend an approach that is the most cost-effective considering the effort involved and the accuracy of the output. Guidance on using the lumped technique for Green Infrastructure will be developed for inclusion in the SWMM user's manual.

3.4 Task 3: Create interface between SWMM and Decision Support Tools

The simplest interface between SWMM and Decision Support Tools is an ASCII text file containing size, number, and performance of BMPs and Green Infrastructure components from a SWMM model run. We will create both a text file capability and an Application Programming

Interface (API) that allows direct connection between SWMM and Decision Support Tools developed by external agencies/industries.

3.5 Background for SWMM Green Infrastructure

3.5.1 The demand for Green Infrastructure

There has been a recent paradigm shift in the way that stormwater is managed from one that focuses on regional end-of-pipe systems to practices associated with Low Impact Development (LID). The LID drainage components are frequently described as Green Infrastructure (e.g., swales, rain gardens, vegetated filter strips) to distinguish them from their gray infrastructure counterpoints (e.g., reinforced concrete pipes, hardened channels, etc.). There is a substantial demand among the modeling community for SWMM to include the capabilities to represent these new practices. In many cases SWMM is being used to evaluate various scenarios that include both gray and green measures to reduce combined sewer overflows. This results in a demand for tools that allow optimization of the scenarios to minimize construction and operational costs. The approaches outlined in Tasks 1 and 2 (§3.2, 3.3 above) will create a practical and adaptable model to meet these needs.

3.5.2 The number of Green Infrastructure practices is multiplying

There are currently seven Green Infrastructure practices that can be modeled in SWMM, including permeable pavement, rain gardens (bioretention), green roofs, street planters, rain barrels, infiltration trenches, and vegetated swales. Variations of these practices are continuously being developed and implemented by innovative communities, so we need to be able to predict their impact on runoff rate, quantity, and quality. The processes operating in a bioretention system include infiltration, sedimentation, filtration, ion exchange, biological uptake, evapotranspiration, and storage. All of the other Green Infrastructure processes include either some or all of these processes. Thus, rather than continually developing new Green Infrastructure features, there is a need for a single generic feature that can be modified to represent infiltration, sedimentation, filtration, ion exchange, biological uptake, evapotranspiration and storage with different coefficients to create different models. In Task 1 (§3.2), we will use the existing bioretention cell in SWMM as a template for an adaptable Green Infrastructure algorithm. We will develop a standardized approach to other Green Infrastructure features using this template.

3.5.3 The problems of "what if" and sustainability

There is widespread interest in using SWMM to help decision makers develop the most cost effective solutions for TMDL compliance and reduction of CSOs. Our expectation in the near term is that the decision support tools will exist independently of SWMM and operate by having SWMM execute a variety of scenarios, which can then be evaluated in terms of the pollutant removal and cost effectiveness. As discussed in Section 6B Code Development (pg 25), we expect that the modularization of the codes will produce opportunities to create more automated approaches to running multiple models for sustainability analysis.

Practical simulation of distributed Green Infrastructure for sustainability analysis poses a number of practical challenges:

1. The identification of distributed BMPs, their specific designs and the areas they treat from the overall watershed they are within can be difficult and prone to inaccuracies.

2. The quantity of individual units potentially present in a watershed can result in a prohibitively large quantity of inputs and prohibitive computational requirements if each must be simulated explicitly.
3. Any method of "lumping" distributed BMPs (or their effects) and their drainage areas have the potential to result in a loss of model utility and the introduction of bias.

Considering these factors, tradeoffs must be made to meet desired functionality while simultaneously minimizing user input requirements, computational expense, and time. The Water Environment Research Foundation Report by Co-PI Barrett and Rowney (Barrett et al., 2012) investigated a variety of techniques to represent individual BMPs in a more lumped fashion including a watershed model parameter adjustment approach and a hydrograph post-processing approach. These approaches are implemented in Task 2 (§3.3 above).

Existing decision support tools could include benefits explicitly associated with pollutant reduction, as well as the benefits associated with other ecosystem services that can be modeled using SWMM. What is needed to facilitate the use of such tools is the development of a module that can pull the BMP and Green Infrastructure data from SWMM and provide these to another model. Decision support tools could then access this file to calculate a whole life cost that includes both initial capital costs and long-term maintenance costs. This approach is implemented as our Task 3 (§3.4 above)

4 Biofilm Modeling algorithms for distribution pipes

4.1 Overview

The goal for the Center's Biofilm project is to make the state-of-the-art in biofilm modeling available in EPANET-MSX. The Center will efficiently accomplish this goal by adapting the biofilm model algorithms in the open-source AQUASIM code to EPANET. Note that a key part of this adaption is linked to changing the EPANET transport algorithm from Lagrangian to a sub-segmented Eulerian approach. The segmented Eulerian approach is necessary to obtain spatial gradients in biofilm properties over pipe lengths between the junction nodes. This associated code development task is part of this proposal Section 6B: Code Development (pg 25).

Integration of AQUASIM into EPANET-MSX will consist of the tasks, products and outcomes shown in the accompanying boxes. Details on these tasks are described in detail in the following subsections. Detailed explanation and background for biofilm modeling can be found in §4.3 below.

Tasks for Biofilm Modeling

1. Define AQUASIM and EPANET-MSX equivalencies.
2. Transfer the AQUASIM numerical algorithms into EPANET
3. Develop standard biofilm descriptions.
4. Create application case studies.

4.2 Details of Biofilm Modeling Tasks

4.2.1 *Task 1: Define AQUASIM and EPANET-MSX equivalencies*

Define the cross-connections between data structures in AQUASIM and EPANET-MSX. The two models use different data structures and naming algorithms for otherwise identical variables. We will produce a semantic map between the codes that will be useful both to this project and for any future work to merge these models.

4.2.2 *Task 2: Transfer the AQUASIM numerical algorithms into EPANET*

Integrate the numerical solution algorithms from AQUASIM into EPANET. Examine algorithm performance and modify to increase the efficiency and stability. This task will initially be accomplished using the existing Lagrangian transport structure within EPANET so that comparisons direct comparisons can be made to before/after for model testing. Full implementation of Eulerian transport (Section 6B Code Development, pg 25) in EPANET will be used to include spatial gradients of biofilms along pipes.

Products and Outcomes for Biofilm Modeling

1. Technical Report comparing data structures in AQUASIM and EPANET-MSX, and outlining numerical approach to adapting AQUASIM into EPANET (Tasks 1 and 2).
2. Open-source biofilm code with documentation (in-code commenting) for EPANET (Task 2).
3. Technical Report (User Guide) on applying standard biofilm descriptions within the new EPANET biofilm module (Task 3).
4. Technical Report on case study to test and validate biofilm

4.2.3 *Task 3: Develop standard biofilm descriptions*

Several standard biofilm descriptions will be developed as examples to help new users apply the program successfully with an acceptable training investment. This task is seen as vital to the EPANET community because AQUASIM's approach can be a bit daunting to the uninitiated.

4.2.4 *Task 4: Create application case studies*

Application case studies will be created using existing data. These case studies might range from operating water distribution systems to pilot-scale pipe loops. The case studies and results will be stored in the Center's Case Library (Section 6A Community Outreach and Support, pg 10). Background and Justification for Biofilm Modeling

4.3 Details and Background for Biofilm Modeling

Shang et al. (2008) developed the multi-species extension to EPANET, known as EPANET-MSX, to greatly enhance the program's capabilities for water quality modeling in drinking water distribution systems. The program presently tracks over time and space multiple chemical species (including bacteria) in both suspended and wall-attached states. The program can also account for liquid-film mass transport resistance between the bulk fluid and the wall reactions. Unfortunately, it cannot simulate diffusive mass transport within a wall-attached biofilm. Therefore, the program is only applicable when very thin biofilms are present on the pipe surface (i.e., where diffusive transport resistance within the biomass is insignificant).

EPANET-MSX could take another major step forward in its capability for distribution system modeling through the addition of a comprehensive biofilm simulation algorithm. This is not a trivial undertaking, however. Another phase (i.e., biofilm phase) has to be added to the program with one-dimensional diffusive transport in the biofilm, and biofilm growth and decay has to be accounted for, along with bacterial erosion off and deposition onto the biofilm. Also, the addition of a biofilm phase increases the complexity of the numerical solution considerably. As such, it seems that the best way to move forward is to integrate an existing biofilm model into EPANET, rather than developing a new one. Fortunately, the code for AQUASIM, which was developed by Reichert (1998), has recently been placed in the public domain. AQUASIM has a robust biofilm modeling capability and has been used for many years to successfully simulate biofilm systems.

As noted by Reichert (1998), AQUASIM conceives of a biofilm as a solid matrix with pore water that can contain dissolved chemicals or suspended solids. Diffusive mass transport resistance within the biofilm is accounted for, and any transformation processes can be defined. The growth or decay of organisms forming the solid matrix results in the expansion or shrinkage of the biofilm thickness. Solids (e.g., bacteria) can attach or detach at the biofilm/water interface or from within the depth of the biofilm. In short, AQUASIM is a very comprehensive model that allows for multiple approaches in characterizing biofilm processes.

As the open-source AQUASIM model includes the biofilm processes missing from EPANET-MSX, the integration of these processes (Tasks 1, 2 and 3 above) is the simplest and most direct approach to obtaining this capability.

5 Common Numerical Core for matrix solver

5.1 Overview

To ensure that the long-term development of SWMM and EPANET can easily take advantage of new advances in computer power, we will develop a high speed solver as a common numerical core for the computational engines for both models. The state-of-the-art in numerical solvers for water infrastructure systems is decades behind the approaches used in microprocessor circuit networks (see discussion in §5.3 below) and we will use cross-disciplinary technology transfer to achieve massive speed up of the present solvers.

The motivation for this idea is the recognition that our water infrastructure, whether stormwater, sewage, or potable water distribution, is fundamentally composed of pipes, open channels, and reservoirs in a network. These are represented as a topology of connected nodes and segments in a system with different characteristics and equations for each segment and node. Regardless of the type of segment or node (pipe, open channel, reservoir), their flow solution is through a set of coupled, nonlinear, partial differential equations (PDE). From a numerical perspective, the solution of coupled network PDEs does not depend on the type of system, but on the stiffness and nonlinearity of the resulting matrix equation. Instead of using two solvers, each tuned to the *perceived* stiffness and nonlinearity problems of stormwater vice distribution piping, we will use a single solver that adjusts its solution method based on analysis of the stiffness and nonlinearity of the user's particular system.

5.2 Approach and Activities for Common Numerical Core

Unlike the Green Infrastructure tasks (§3), the fundamental needs, requirements and implementation studies have not been completed for a Common Numerical Core; and unlike the Biofilm tasks (§4), there is no obvious existing code that should be integrated into the system[1]. Therefore, we will proceed in this area with the QA/QC approach for code development as outlined in Section 7 Quality Management Plan (pg 55), which results in the tasks, products, and outcomes outlined in the accompanying boxes. The selected numerical approach will be designed for: (i) parallelization on multi-core, hyperthreading workstations, either through MPI or OpenMP, depending on which approach is more favorable; (ii) effective implementation on GPU workstations; and (iii) adaptability for new nonlinear features (e.g. new types of pumps, pipe elements, or channel features with non-standard behaviors).

Tasks for Common Numerical Core

1. Write a white paper on generalized numerical algorithms for solving nonlinear network partial differential equations. The focus is to propose a generalized algorithm or existing solver that can be applied to the SWMM and EPANET sets of coupled equations as a common numerical core.
2. Commission an external review of white paper on the common numerical core that focuses on practicality, stability, and solution speed for a variety of computer systems.
3. Hold a community workshop to evaluate the proposed common numerical core with an emphasis is on long-term adaptability.
4. Commission either an external or internal expert on numerical algorithms to write or adapt an open-source numerical solver to be used with EPANET and SWMM.
5. Create and conduct a validation program (either internal or external) for the common numerical core.
6. Implement the core within the modularized SWMM and EPANET models and conduct final validation testing.

5.3 Background for Common Numerical Core

5.3.1 Increasing memory, processors and speed

In the past, solution of unsteady, nonlinear PDEs was hampered by lack of sufficient memory and computer speed. To work around these problems, numerical methods were developed around linearized solutions and/or using peculiarities of the selected numerical discretization to speed solutions. Today, a computer with 256 GB of memory running at 3 Ghz with 12 CPU cores and 4000 GPU cores can be purchased for less than $10,000 (PI Hodges recent experience). Such workstations are likely to see common use as engineering workstations throughout industry within the initial 5 years of the Center, and will likely be consumer desktop machines within 10 years. Thus, in thinking about the future of EPANET and SWMM, we need to be aware of the steadily increasing computational power that will be available and how effectively the model computational engines use this power.

[1] However, we do have candidate open-source solver codes for investigation.

5.3.2 *Numerical Solvers in SWMM and EPANET*

The EPANET computational core is a sparse-matrix solver of the linearized coupled hydraulic equations for flow and head in a piping link/node system, which code documentation indicates uses the GSFCT and GSSLV approaches from George and Liu (1981). The solver is invoked with an iterative Newton-Raphson approach proposed by Todini and Pilati (1988), which has been used extensively in other pipe network modeling. The SWMM computational core use a Newton approach for the kinematic wave approach and Picard iterations for coupled explicit continuity and momentum. These approaches have a long history, but were designed at a time when computers were severely memory-limited.

Products and Outcomes for Common Numerical Core

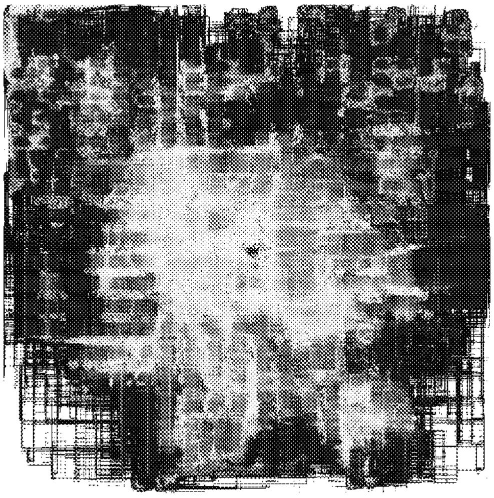
1. White paper on common numerical core algorithms
2. External review report and community-recommended modifications of common numerical core algorithms.
3. Open-source code and documentation (in-code commenting) for numerical core.
4. Technical Report (User and Programmer's Guide) for common numerical core, including methods for adaption to new nonlinear features.
5. Technical Report on validation and testing of common numerical core.
6. Technical Report (User Guide) on implementation of common numerical core in EPANET and SWMM.

5.3.3 *A Quantum Leap using Methods from Semiconductor Microprocessor Network Design*

We can effectively use a Newton approach with "Jacobian bypass" method for rapid implicit solution of these matrix equations. PI Hodges has demonstrated that an accelerated Newton method could be used with a 4-core Xeon 5160 desktop computer running at 3 GHz with 16 GB of memory to solve a full Saint-Venant solution of a river network with 1.3×10^5 nodes and achieve simulation results 300x faster than real time with a nominal 6 minute time step (Liu and Hodges 2014a). This type of speed with the Saint-Venant equations can be translated directly to speed-up for solutions for EPANET and SWMM.

The approach of Liu and Hodges (2014a) is built on recognition that numerical solvers have dramatically changed over the past two decades – although not in water resources. In particular, the electrical engineering community involved in Very Large Scale Integration (VLSI) for semiconductor circuit design has been handling network problems on the order 10^8 to 10^9 nodes in complex circuitry (Figure 6C-2) as a daily design task. Each time a change is made in circuitry during the design process, a massive number of simulations for different unsteady circuit conditions must be run.

As illustrated by Hodges and Liu (2014a), one can draw direct parallels between water flow in networks and electric circuits, which, by the way, is not a new idea, e.g. Brownell (1895) used pipe flow to explain the electrical function of a Wheatstone bridge. This parallel seems to have been forgotten in water infrastructure networks, and there exist a wide range of untapped potential in the computational methods used in microprocessor design. PI Hodges has had an unfunded and informal collaboration with Dr. Frank Liu, an electrical engineer at IBM Research Austin for the past 5 years. This continuing collaboration has resulted in Liu and Hodges (2012, 2014a, 2014b), Hodges and Liu (2014a, 2014b), with further work in progress.



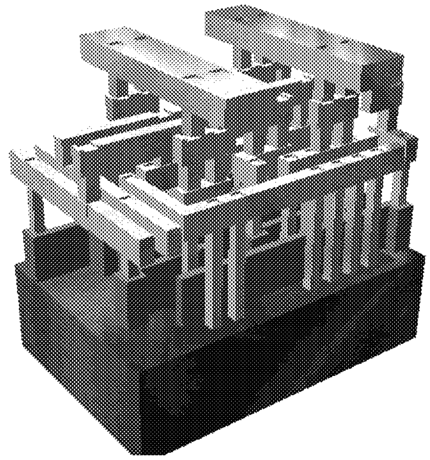


Figure 6C-2: At left – connection network of a VLSI microchip; at right – 3D view of wires in a VLSI chip without dielectric insulation. These systems are more complex in their connectivity and nonlinearity than any water networks attempted with EPANET or SWMM. Nevertheless, there are similarities in matrix solutions and these massive systems are routinely solved in Computer Engineering. http://visicad.eecs.umich.edu/BK/FGR/ad4-2d-cong.png, http://en.wikipedia.org/wiki/Standard_cell.

6 Adaptable computational framework for security, real-time monitoring, sensors, and control

A long-term objective for the Center is a suite of modules for SWMM and EPANET that allow the models to be used within a comprehensive security and risk-assessment framework that includes real-time monitoring, feedback from sensors, along with system control. These efforts will require substantial cooperation from EPA, Homeland Security, U.S. Government laboratories and businesses that have significant expertise in these areas. Furthermore, given the complexities involved in these issues, it seems ineffective to develop and implement such strategies in the legacy code; particularly because the modularized code (Section 6B: Code Development, pg 25) will be easier to work with in implementing security controls. A critical issue with the legacy codes is the lack of Eulerian Transport algorithms in EPANET, which make it more difficult to effectively implement security and source-tracking schemes that depend on transport along pipe lengths. That is, with the SWMM and EPANET legacy codes, security and real-time monitoring implementations would be substantially different and would have relatively few commonalities. Thus we plan to wait until our code modularization is well underway and we have developed the Eulerian Transport algorithm for EPANET before we commence work in this area. However, this plan is open for discussion with the broader model user community and could be moved forward and given higher priority by the Center.

Our initial focus in this area is development of a white paper that identifies the types of algorithms that are needed for the models, interfaces requirements for external data, sensors, and control outputs. In the Year 3, co-PI Berglund (NCSU) will conduct a review of the state-of-the-art approaches for managing security of water distribution systems and issues for integration with EPANET and SWMM. In addition, the Center has set aside unallocated funds that can be used to subcontract other experts to participate in projects such as this review. The review will cover problem statements and solution approaches for comprehensive risk assessment, source identification, event detection, sensor network design, threat management strategies, water advisory simulation, and real-time simulations. Additional topics may be identified in conjunction with EPA and stakeholders. The research team will develop a white paper describing their findings. If additional resources become available, the research team will extend their efforts towards implementation of issues identified in the white paper.

Tasks/Products/Outcomes for Security, Real-time Monitoring, Sensors and Control

Prepare a white paper (technical report) studying needs, requirements and implementation approaches for security, real-time monitoring, sensors and control in SWMM and EPANET.

Host a community workshop to consider implementation strategies.

We believe the long-term success for effective and numerically efficient security, real-time monitoring, sensors, and control will be achieved with a common 1D momentum and continuity solution for both networks, as discussed in Proposed Future Developments §7.2 below – a task that will build on the Common Numerical Core, §5, above.

7 Proposed Future Developments

7.1 Overview

Our accomplishments in Novel Research during the first 5 years will be to address immediate needs of the community (Green Infrastructure, Biofilms) and make a quantum leap in computational speed by employing numerical solution methods developed in microprocessor design. However, there remains a wide range of needed improvements and advances that can be addressed by the Center over the long term. We or others might begin to address some of these issues with the unallocated subcontract awards that we have set aside in the Center budget. Below is our vision:

7.2 Common 1D Unsteady Flow Network Solver

Instead of using the node/link *steady-state* hydraulic balancing in EPANET, we believe that the model can be readily upgraded to solve the fully dynamic unsteady 1D coupled momentum and continuity equations. Building on the Common Numerical Core for matrix solution (§5), we propose a long-term goal should be a Common 1D Network Solver that would be used by both SWMM and EPANET. This effort would have several advantages:

1. We could readily use some of the specialized solution methods from microprocessor design without having to customize the solution methods separately for EPANET and SWMM.

2. True unsteady flow modeling in EPANET would improve its applicability for security, real-time monitoring and control.

3. Code maintenance and upgrading to future computer architectures would be simplified with only a single transport model.

7.3 Follow-on work to security, real-time monitoring, sensors and control

Results of the proposed work will provide a roadmap for meeting the needs, requirements, and implementation approaches for security, source-tracking, real-time monitoring, sensors and control. We intend to pursue all of these issues within the modularized, high-speed code produced by the Center. An issue that we believe will be important is creating secure "selective availability" with custom code for cities. With the modularized code, it will be straightforward for a city or organization to create a private code module that hides specific feature that should not be made open as a matter public safety.

7.4 EPANET for Multi-Story buildings

Making EPANET tractable for multi-story buildings will be able to build on our outreach work to the Building Information Modeling community. By the end of year 4, we will have a good understanding of how to transfer BIM data directly to EPANET. Combining these data input with the improved speed of the Common Numerical Core should allow EPANET to be tested and modified for 3D buildings. Combined with the Eulerian Transport algorithm and advanced biofilms models, tools can be created for doing full water quality analysis of hospitals or other large building complexes. However, we believe the most effective 3D EPANET applications will only occur after development of a true unsteady solver (i.e. §7.2).

7.5 Linking SWMM with 2D models

PI Hodges has extensive experience in 2D and 3D hydrodynamic models (e.g. Hodges and Rueda, 2008; Hodges 2014), and we would like to use this expertise to develop fast computational linkages between urban surface models and SWMM. In particular, backwater and flooding effects in urban areas due to pressurized storm drains and flash flooding effects can only be handled with effective linkages between 2D shallow water flow solutions of surface water and unsteady 1D dynamic equations in storm sewers. UT is presently working on mobilizing a 3D ground-based lidar set that provides sub-centimeter resolution of UT campus streets and sidewalks. PI Hodges and collaborators are doing the preliminary work to develop improved surface runoff models from this highly-detailed landscape data.

7.6 Automated data extraction from Civil Information Modeling (CIM) and Building Information Modeling (BIM)

By the end of year 4, our understand of BIM and CIM will allow us to propose new approaches for automated data extraction from BIM/CIM models. This provides the potential for rapidly creating EPANET models in buildings as well as both distribution and stormwater models through an urban area.

8 Contributions to Innovation and Sustainability

This subproject is focused almost entirely on innovation, which we will not belabor here. We will provide key advances in modeling Green Infrastructure, Biofilms and model speed-up. We will set the stage for future improvement in security, real-time modeling, sensors and control.

Sustainability of the Center

The innovations above will contribute to the sustainability of the Center by providing greater speed, adaptability, and functionality of the models, which will create a greater demand for the Center's expertise in developing further innovations.

Sustainability of the Models

The approach used for Green Infrastructure provides an adaptable framework for future modifications with different types of BMPs. The ease of adaption makes the model inherently more sustainable. The Common Numerical Core will make the models more readily adaptable to future developments in computer architecture as only a single solver will need to be modified.

Water Infrastructure for Sustainability

The Green Infrastructure module with lumped distribution of BMPs will make SWMM a more practical tool for sustainability analysis

9 Expected Results, Benefits, Outputs and Outcomes

The **expected results** from this subproject will be implementation of new EPANET and SWMM features and capabilities, with an improved understanding of the next steps in security, real-time monitoring, sensors and control for the models.

The **outputs** from this subproject are:

- SWMM code for Green Infrastructure that is adaptable and extensible.
- New capabilities for Biofilm modeling in EPANET-MSX and extended capabilities in the new modular EPANET with sub-segmentation and Eulerian transport.
- A faster model computational core that is common to both models
- A study of model needs, requirements, and implementation strategies for security, real-time monitoring, sensors and control for EPANET and SWMM.

The **benefits** of this subproject are in providing new features and capabilities for the models with an underlying improvement in code speed.

The long-term **outcome** of this subproject will be a solid, high-speed, numerical foundation for EPANET and SWMM that will allow the models to be used for more extensive sustainability studies with Monte-Carlo simulations and large systems.

10 General Project Information

10.1 Project team and management

This project will be directly overseen by PI Hodges. Coding will be done by a post-doctoral scientists and PI Hodges (who is hands-on with model codes). Co-PI Barrett will oversee the Green Infrastructure task with assistance of co-PI Rowney. Co-PI Speitel will oversee Biofilm modeling. Co-PI Cleveland will work with the team to ensure the new models will work with both the legacy codes and the new modularized EPANET and SWMM. Co-PI Berglund will develop the white paper on security, real-time monitoring, sensors, and control. UT has recently hired (starting Jan 2015) a professor whose expertise is in civil infrastructure sensors (senior person C. Claudel) who will work with the team on cutting edge technology – his recent work is in inexpensive biodegradable sensors that might be valuable for diagnosing water infrastructure security issues.

10.2 Facilities

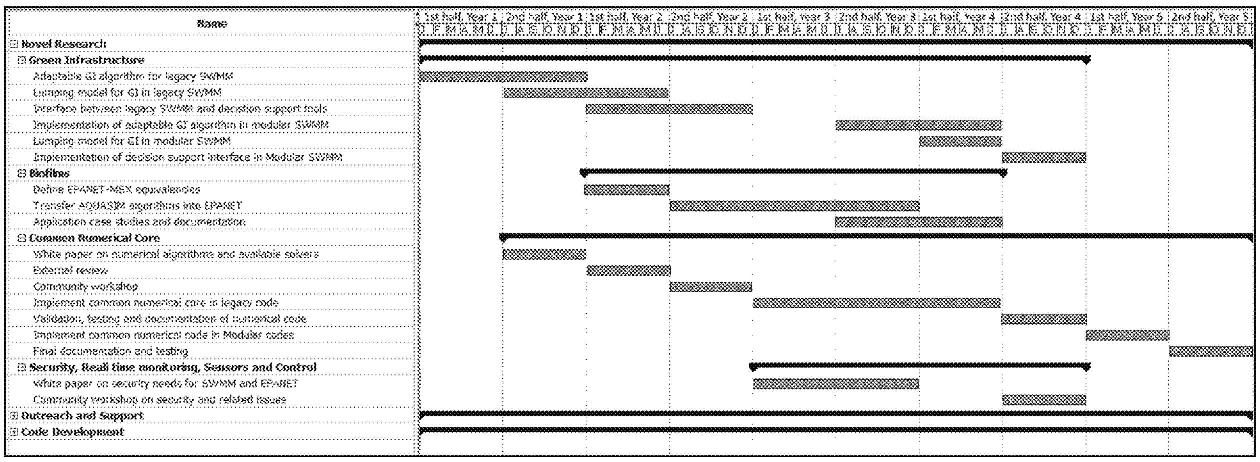
The code development efforts in this subproject require standard desktop workstation, which are available at the Center for Research in Water Resources at UT Austin. Workstations are upgraded on a regular basis. These presently include quad-core Xeon computers with 16 to 64 GB of physical memory operating between 2.5 to 3.3 GHz with multiple boot operating systems for MacOSX, Windows, and Ubuntu Linux. We also have a 12-core Linux machine with 256 GB of physical memory and 4000 processing nodes on GPU cores (2xNvidia Tesla K20).

10.3 Unique capabilities

This team brings unique strengths in the key areas of Biofilms, Green Infrastructure, Security, and Numerical Solvers. In **Biofilms, Dr. Gerald Speitel** has a long history of mathematical modeling of water quality in water distribution systems, and is the ideal person to oversee a post-doctoral scientist in transferring the AQUASIM biofilm models into EPANET-MSX. In **Green Infrastructure, Drs. Michael Barrett and A. Charles Rowney** have literally written the book on implementing Green Infrastructure algorithms (Barrett et al, 2012). They are also uniquely positioned to oversee a post-doctoral scientist in modifying and testing new SWMM code. In **Numerical Solvers, Dr. Ben Hodges** work with IBM Research Austin scientist Dr. Frank Liu has provided innovative approaches to adapting microprocessor electrical circuit design numerical methods for solution of the Saint-Venant equations in river networks. Adapting these fast methods to EPANET and SWMM will be straightforward work that follows on their pioneering collaboration over the last five years. In **Security and source-tracking,** Dr. Berglund (née Zechman) is an expert that has been researching and publishing extensively in this area. Indeed, outside of staff at EPA and Sandia National Labs, she is one of the most-published US academics in this area and is ideally positioned to lead the study in these areas.

10.4 Schedule

An assessment of resource loading, logical sequence, and program requirements was carried out. Based on that assessment, a time schedule was developed. The GANNT chart below provides an outline of a program that delivers the items discussed above.



Note that the collapsed time lines (Outreach and Support and Code Development) are provided in their respective sections.

7 Quality Management Plan

7.1 Summary

The Quality System is focused QA/QC of new model code and bugfixes produced during the model life cycle, along with the associated documentation. The model life-cycle will follow a Quality Assurance Project Plans (QAPP) developed by Task Leaders, approved and overseen by Subproject Lead PIs and the Quality Manager. The primary QC approaches are: (1) using the method of manufactured solutions (Roache 2002; Knupp & Salari 2010) for code verification, and (2) using real-world data for model validation. Any change to the code requires both the method of manufactured solutions and real-world validation comparisons before it is accepted into published code.

The QAPP and the QC products will be peer-reviewed and/or provided with online community comments, depending on the scope of changes (i.e. larger scoped changes will be subject to peer review, whereas small bugfixes require only community comments). Note that the Community Outreach with the online Model Portal will allow extensive community involvement in writing code and testing the models (see Section 6A Outreach and Support, pg 10). User-provided model updates and bugfixes will be immediately available for all to use, but will not be put into an official model release until the new code has been run through the QA/QC process.

7.2 Organization and Management

The Center will implement a Quality System with an overall Quality Management Plan and an EPA approved for model development that meet the standards of EPA QA/G-5M *Guidance for Quality Assurance Project Plans for Modeling*. The organization and responsibilities in the Quality System are shown in Figure 7-1. Each new code development project is separated into phases of theory/coding/validation. Each phase is structured with peer-reviewed reports and/or community workshops. Because SWMM and EPANET may be used for regulatory compliance and can potentially be involved in litigation and/or Congressional testimony, the QAPP for model development will meet the highest QA/QC standards. Note that different stages of model development may be carried out by different entities, including Center participants at UT, co-PI's at collaborating programs, or through external grants extended to organizations outside the Center. To ensure that this range of entities produces both timely and quality results, the Center management will include strict QC enforcement.

7.3 Quality System

The Center's research activities will be evaluated through a formal QAPP process including peer review and community comments. These activities will be both on the front-end QA of the process (developing the QAPP) and at the back-end for QC of draft products. QA practices will be developed in the QAPP by a team comprised of the Task Lead, the Subproject Lead, and the Quality Manager, who will work with both the Model Expert Panel and the Center Executive Committee. Feedback from peer review and community comment will be reviewed by the Task Lead, the Subproject Lead PI, the Model Expert Panel, and the Quality Manager to determine the path forward in modifying draft products and/or the QAPP as necessary. Training and supervision for the QA process will be overseen by the QA Manager. The general approach to modifying QA procedures will be through analyses of bugfixes during code life cycle – although latent code bugs are common in software, they can be interpreted as a failure of the QA/QC system of the original code.

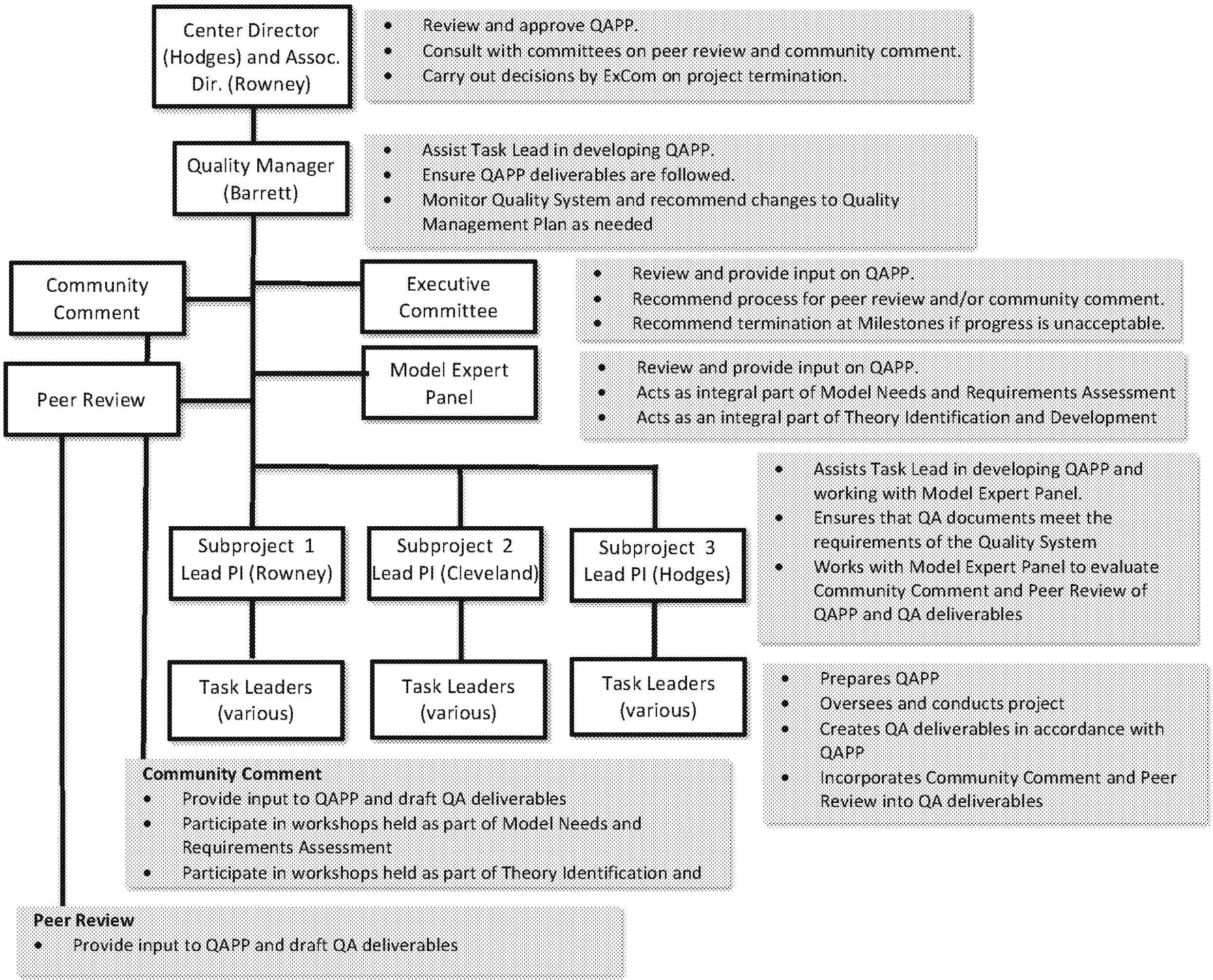


Figure 7-1. Quality management responsibilities for the Center. Personnel assigned to the Task Leader positions that are responsible QA/QC at lowest level are shown in the Center Organizational Chart in Section 10, Administrative Unit, (pg 64).

7.4 QA for Novel Research and Code Development

Each model development and modularization project will require a QAPP with the components outlined below. The Quality System is designed to meet the requirements of EPA QA/G-5M by: establishing a systematic planning process (§7.4.1); using peer-reviewed theory and equations (§7.4.2); documenting theory, assumptions and parameters (§7.4.3); ensuring that the model uses appropriate and obtainable input data and parameters (§7.4.4);, evaluating the types of model output required for model usefulness (§7.4.5); documenting changes from the original QA plan (§7.4.6), and establishing life-cycle process for code management (§7.4.7).

The QAPP for a specific model development project will contain four components, illustrated in Figure 7-2. The Center will conduct model development using these four components as discrete tasks that can be assigned to Center co-PIs or subcontracted to other entities who, in the judgment of the Center Executive Committee, can provide the needed expertise for a particular

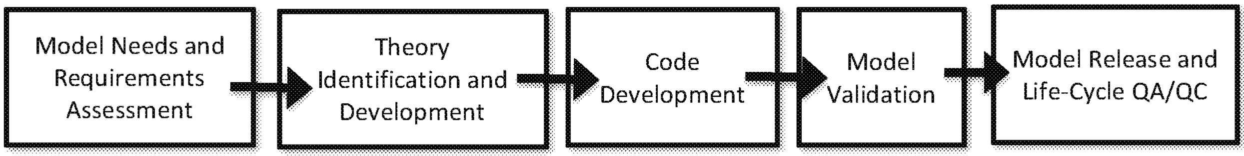


Figure 7-2 QA/QC for model development

task. Our approach allows the Center to assign tasks to the most efficient organization for each step of the project, rather than assigning the entire model development project to a single entity.

The steps in the Model Needs and Requirements Assessment (see box) provide a systematic process for identifying the model capabilities and needs for improvement. Substantial communication with both discipline experts and the broader community of users, programmers, and stakeholders ensures we will identify model improvements that are useful and achievable within available budgets.

Theory Identification and Development (see box) provides a systematic planning process for documentation before, during, and after coding. The goal is to ensure that code: (i) matches theory, (ii) is written cleanly, (iii) has sufficient commenting, and (iv) has adequate technical reports for another programmer to understand. The steps outlined comprise part of EPA's Model Design, all of the Model Coding, and part of the Model Testing requirements (EPA QA/G-5M, pg 18)

The Model Validation process (see box) illustrates how model will move from its initial calibration and tests during code development to producing a code that can be confidently released to the public.

7.4.1 Systematic planning process

The SWMM and EPANET model improvements will be conducted through coordination of multiple organizations. In our view, a separate QAPP for each major model development project will be desirable (e.g. Biofilms, Green Infrastructure). These QAPP will all follow a similar outline, so that the effort involved in

Model Needs and Requirements Assessment

1. Define the *existing* model capabilities.
2. Define the *needed* capabilities (including output specifications and allowable uncertainty), through meetings of experts, online community forums, and/or workshops.
3. Define the objectives and quality performance criteria for the new capabilities in a draft **Model Needs Technical Report.**
4. Provide an opportunity for community comment through a workshop and/or open online discussion.
5. Revise the **Model Needs Technical Report** and provide online.

Theory Identification/development

1. Develop the theory and equations for model improvements from scientific/engineering literature and write a technical report for model improvement.
2. Document the type/extent of input data that is required and the output data that is expected from the theory.
3. **Milestone:** Examine whether these equations and theory can meet the objectives, quality performance criteria, and capabilities from the Model Needs Technical Report. If unachievable, then stop the project here.
4. Produce a draft **Theory Technical Report**.
5. Have the draft Theory Technical Report peer-reviewed.
6. Provide opportunity for community comment through a workshop and/or open online discussion.
7. Consider outside comments and produce the final **Theory Technical Report**.

Milestone: obtain approvals to move forward.

creating a new QAPP will not be extensive. The QAPP will be developed in a collaboration between the Center an external investigators as a method of ensuring that all parties are clear on the needed tasks and documentation for QA.

Clear and consistent objectives will be developed in the QAPP for each model improvement project. The objectives will follow a systematic process for defining model needs and requirements, theory identification and development, code development, and model validation. Each major milestone will require documentation and approval by the Model Expert Panel and the Executive Committee of the Center. When the Model Innovation Panel and the Executive Committee do not believe the model improvements are achievable, the project will be stopped.

7.4.2 Peer reviewed theory and equations

Model development will rely on theory and equations primarily from peer-reviewed literature, but it is recognized that some valuable scientific results never actually reach peer-reviewed status. The development of model theory will include external peer review of the equations to be implemented – whether or not the equations have been previously peer-reviewed. The Center intends to rely on peer reviewers who are provided with an honorarium as we expect the efforts in peer-review of these documents to require more substantial effort than is typically applied to journal articles.

7.4.3 Documentation of assumptions, theory and parameterization

Each phase of the QA plan requires production of quality documentation that can be understood by both programmers and model users. Documentation will be peer-reviewed and/or provided online for community comment.

7.4.4 Appropriateness of parameters and obtainability of input data

During both the Model Needs and Requirements Assessment and the Theory Identification and Development phases, the QA process will

Code Development

1. Examine numerical and coding approaches used in prior models.
2. Determine the numerical implementation of the theory that will be used.
3. Develop a code testing strategy to provide preliminary validation of the completed code.
4. **Milestone:** Write a **Code Implementation Technical Report** for committees, peer review and comment.
5. Develop a chart of variables to be added, their storage locations, and relationships to existing variables in the code.
6. Develop and flow chart a strategy for implementing pieces of the new module for testing as the project progresses.
7. Update the **Code Implementation Technical Report**.
8. Develop new modules to implement the theory; include detailed in-line commenting of code and updates to the **Code Implementation Technical Report** that explain the coding choices that depart from the original plan.
9. Test each module portion using the Method of Manufactured Solutions, which ensures that model code exactly reproduces the desired numerical implementation.
10. **Milestone:** Perform preliminary calibration and validation of code in accordance with strategy determined at the beginning of the project. If the code cannot be calibrated or validated, the viability of the project must be reviewed.
11. Revise the draft **Code Implementation Technical Report.** This document must include discussions of limitations of the model associated with choices in the numerical method.
12. Have the draft Code Implementation Technical Report peer-reviewed and made available for online comment and/or a community workshop.
13. **Milestone:** Revise and submit a final **Code Implementation Technical Report**.

examine the parameters required to execute the desired theory in a model and the input data that would be required. The QA process will be focused around the questions: 1) can the Center obtain enough data to reasonably set the model parameters?, and 2) can a user reasonably obtain the input data necessary to run a model based on the proposed theory? During the code development phase, the QA process will ensure that any changes the numerical implementation requires does not significantly expand the input data or parameterization requirements.

Model Validation

1. Develop a **Validation Plan** and submit to the Model Innovation Panel and Executive Committee for external peer-review and/or online comments. This Validation Plan will include description of separate calibration and validation test cases to be used, data sources, and the quality objectives that the model should achieve and evaluation of uncertainty in results (these should be consistent with the original Model Needs and Requirements Assessment).

2. **Milestone:** Modify the Validation Plan in light of comments, and submit to the Model Innovation Panel and Executive Committee for approval.

3. Conduct model validation in accordance with plan.

4. Document model behavior and ability/inability to meet the quality objectives and uncertainty evaluation in a draft **Model Validation Technical Report.**

5. Have the draft Model Validation Technical Report peer-reviewed and made available for online comment.

6. Milestone: Revise and submit a final **Model Validation Technical Report.**

7.4.5 Appropriateness of output data

During the Model Needs and Requirements Assessment stage, the QA process will ensure the planned model output meets the community needs. During the Theory Identification and Development phase and the Code Development phase, the QA process will ensure that the model can actually produce the desired output data. During the Model Validation phase, the QA process will examine the quality of the actual output and the uncertainty associated with the output.

7.4.6 Changes from original QA plan

The QA plan will be updated at each major task, i.e. after completion of Model Needs and Requirements Assessment, again after Theory Identification and Development, again after Code Development, and finally after Code Validation a QAPP for the completed project will be updated and archived with analysis of the final code. At each stage, the updated QA will (i) refine the QAPP requirements, (ii) identify new problems or limitations, and (iii) document changes to the model theory, requirements, or QA plan.

7.4.7 QA for Code Maintenance

Code Maintenance begins when a model (or model update) has been moved to public distribution. This requires two principal tasks: (1) fixing latent bugs that are reported by users, following the process, and (2) identifying promising user-written code that could be incorporated into a future official model release, These processes will be developed as part of the QAPP.

7.5 Documentation and Records

Data management for the Center is presented in the Data Plan (see Section 9, pg 61). All QA reports and records generated by the Center investigators and technical personnel pertaining to Center matters will be maintained as Center records in electronic media. Records and documentation distribution will be made as determined by the QA Manger in consultation with the PIs and Center Executive Committee. The QA Manager will maintain a distribution information database for allowable QA access.

8 Human Subjects Research Statement

The proposed research does not involve human subjects in any subproject or administrative function. Assessments on learning, outreach, or educational materials will not involve intervention or interaction with individuals, nor will any information collected be individually identifiable.

9 Data Plan

9.1 Overview and management

The data management plan ensures that data generated from this project will be preserved and available in the future for fostering scientific collaborations, discoveries, and possible industry-academia partnerships based on findings of this proposed research. The Lead PI, Dr. Ben Hodges at The University of Texas at Austin (UT Austin), will be responsible for overall data management. A Data Manager will handled routine data management tasks for the Center under the supervision of PI Hodges. This data plan will be administered by the Data Manager, which will consume about 10% of the time of a post-doctoral position funded by this project (see this proposal Section 10 Administrative Unit, pg 64). Data management efforts will be automated by the Model Portal, which will provide automated archiving and public/password limited access to model code, model input data, validation case study output data, and documentation. The Data Manager will ensure that the Model Portal is both providing access and archiving data appropriately. Maintaining routine working data is the responsibility of Lead PI for each subproject. The Lead PIs will work with the Center's Data Manager to ensure the Center retains long-term archives of all QA products, reports, and data sets that are of interest to the user and programming communities (§9.4 below). In the event that a subproject Lead PI leaves the Center prior to project completion, all data from the subproject will be transferred to the Center and distributed to a new Lead PI.

9.2 Data types, formats, and metadata

Research projects within the Center will generate different types of data, including (i) model code, (ii) model parameterization sets, (iii) validation case study input data, (iv) validation case study output data, (v) community comments, and (vi) peer-review comments. Additionally, data analysis, report documents, presentations, and training materials will be generated. All materials will be maintained digitally. Reports and data sets made public will be provided with a persistent digital object identifier (DOI) for consistent long-term access and citation. All archived data/code will have metadata to document provenance. Metadata standards will be developed by the Data Manager at the start of the project in consultation with the Quality Manager and with approval of the Executive Committee. The standard format for distribution of text documents will be PDF. Companion documents in the application format (e.g. docx, ptpx, rtf, LaTeX) will be maintained within the Center alongside the PDF but in the event of a conflict the PDF will be considered definitive. This two-layer approach ensures that the archived document can be accessed through PDF standards, but the original document processing file can still be accessed for later use in developing training materials. Data format for non-document (data, code) archiving will be either ASCII text files (typically using an XML formatting or comma separated variable) or NetCDF binary. It is anticipated that all community comment data on Center operations (see Section 10 Administrative Unit, pg 64) or developed in outreach and support (see Section 6A Outreach and Support, pg10) , will be captured and maintained in digital form, either directly (e.g., responses to online comment solicitation) or entered manually from non-digital sources (e.g. notes from a workshop). No personal data or information that could be traced to and individual from comments will be sought or stored.

9.3 Working Data storage

Working data for all projects that are not directly in the Model Portal will be stored at the primary institutions where the research will be conducted. Once per year, the Data Manager will arrange a full data exchange to create a duplicate of all external PI working files on the UT servers for the Center. All electronic data will be backed-up at least once a week to external hard drives at each project site.

9.4 Data Archive

The data and relevant research documents from all participants in the Center, along with format instructions for ease of interpretation, will be archived with the University of Texas Digital Repository (UTDR). The UTDR provides the university's commitment to long-term storage and online public availability of research products, accessible at http://repositories.lib.utexas.edu. The UTDR provides perpetual open online access to all the products of the University's research and scholarship endeavors. The UTDR's purpose is to foster the preservation of these digital works for future generations, to promote increasingly rapid advances in scholarly communication, and to help deepen community understanding of the value of higher education. The UTDR has a formal Preservation Policy that commits the university to responsible and sustainable management of submitted works as well as associated descriptive and administrative metadata, by employing a strategy combining: a) Nightly secure backups; b) Storage media refreshment; c) File format migration (including possible migration to new standards). Further details can be found at http://repositories.lib.utexas.edu/policies_preservation. The responsibility for uploading documents to the Center's data archive lies with the Data Manager supervised by the Center Director. The Data Manager will work with the Lead PIs and Task Leaders to ensure that data is uploaded in a timely manner. The Data Manager will ensure that data uploads are in standard formats (§9.2 above) that the UTDR will be able to migrate to future machine-readable data standards.

9.5 Data release

Data and model code developed in the Center's work will all be open source. Data sets used for, and resulting from, model validation will be made public when a new model code is officially released. All QA/QC product reports (see Section 7 Quality Management Plan, pg 55) will be made available in draft form for community comment, and will be archived both as drafts and as final reports after revision for comments. To serve the wide community that includes cities with security concerns, engineering firms with proprietary data concerns, and model developers with copyright concerns, the Center will make available password-protected restricted access sections within the Model Portal (see Section 6A Community Outreach and Support, pg 10). The restricted access sections of the Model Portal will allow users to keep proprietary data that they are using private. However, any data used for validation of code for an official release must be made public.

9.6 Open Source

The license to be applied to software developed by the Center will be agreed with EPA at the outset of the project. The principles to be respected must include protection of the open source nature of the code for public use, but also protect the enablement of commercial extensions to, or interactions with, the code. A number of currently accepted options exist, and the chosen form of license must meet these requirement plus other requirements that prudent practice and/or EPA imperatives may demand. Two alternatives offered to provide a concrete example are a BSD 2-Clause license, and the GNU Lesser General Public License. Both enable commercial extension to the software; some other license templates, such as the GNU General Public License are not as tractable in this area and will be avoided.

This page intentionally left blank

Section 10: Administrative Unit

1 Overview

1.1 Main administration

The overall organization of the Center is illustrated in Figure 10-1 (see next page), with four principal components: an internal executive committee, a suite of external committees, an internal administration group, and a subproject group. The Center administration will be the responsibility of the Center Director, with the assistance of the Executive Committee formed by the Center Director, Associate Director, Quality Manager. Key internal responsibilities for Center staff are summarized in the box at right.

The Center Director has overall responsibility for oversight of Center operations, reporting, integration of the subprojects, budgeting, and liaison with EPA Project Officer. The primary administrative unit for funding and major decisions for the Center is the **Executive Committee** (§ 7.1 below). An EPA representative may be an *ex officio* member (observer without vote, in accordance with Cooperative Agreement) and attend regular Executive Committee meetings in person or via teleconference. The Executive Committee will work closer with a **Stakeholder Committee** (§ 7.2 below) of external advisors to ensure that the direction of the Center operations meets the needs of the communities interested in water infrastructure modeling. The Executive Committee will also work with **Model Expert Panels** for EPANET and SWMM (§ 7.3 below) to coordinate the scientific direction of the work across the five subprojects.

Administrative Support for budgeting, reporting, purchasing, travel, organizing conferences, publications, etc. will be provided by staff at the Center for Research in

Key Internal Responsibilities of Center Staff

Center Director – Supervises the Lead PIs, ensures timely and relevant communication between the subprojects and, in conjunction with the Quality Manager, ensure that projects are delivering quality projects on time.

Associate Center Director – Works closely with the Center Director to keep the Center organized and on-track.

Quality Assurance Manager (see this proposal Section. 7: Quality Management Plan) – Organizes the Quality System and works with Lead PIs in developing QAPP documents and getting quality deliverables through the QA/QC system.

Lead PIs – Responsible for coordination and communication within their subprojects and performance of the Task Leaders.

Task Leaders – PIs or senior personnel who are responsible for performance/oversight of individual tasks to the QAPP standards that are defined at the project inception.

Budget Director – Responsible for tracking Center budgets, deliverables, and project milestones to assist the Center Director and Quality Manager in watching for subprojects or tasks that are falling behind schedule or over budget.

Data Manager – Responsible for day-to-day data management (see this proposal Section 9: Data Plan). This position will be an ongoing part-time (~10%) task of a post-doctoral scientist.

Web Master – Maintains the Center web page. This is a formal position for a MS graduate student that will be an ongoing

Water Resources at UT Austin.

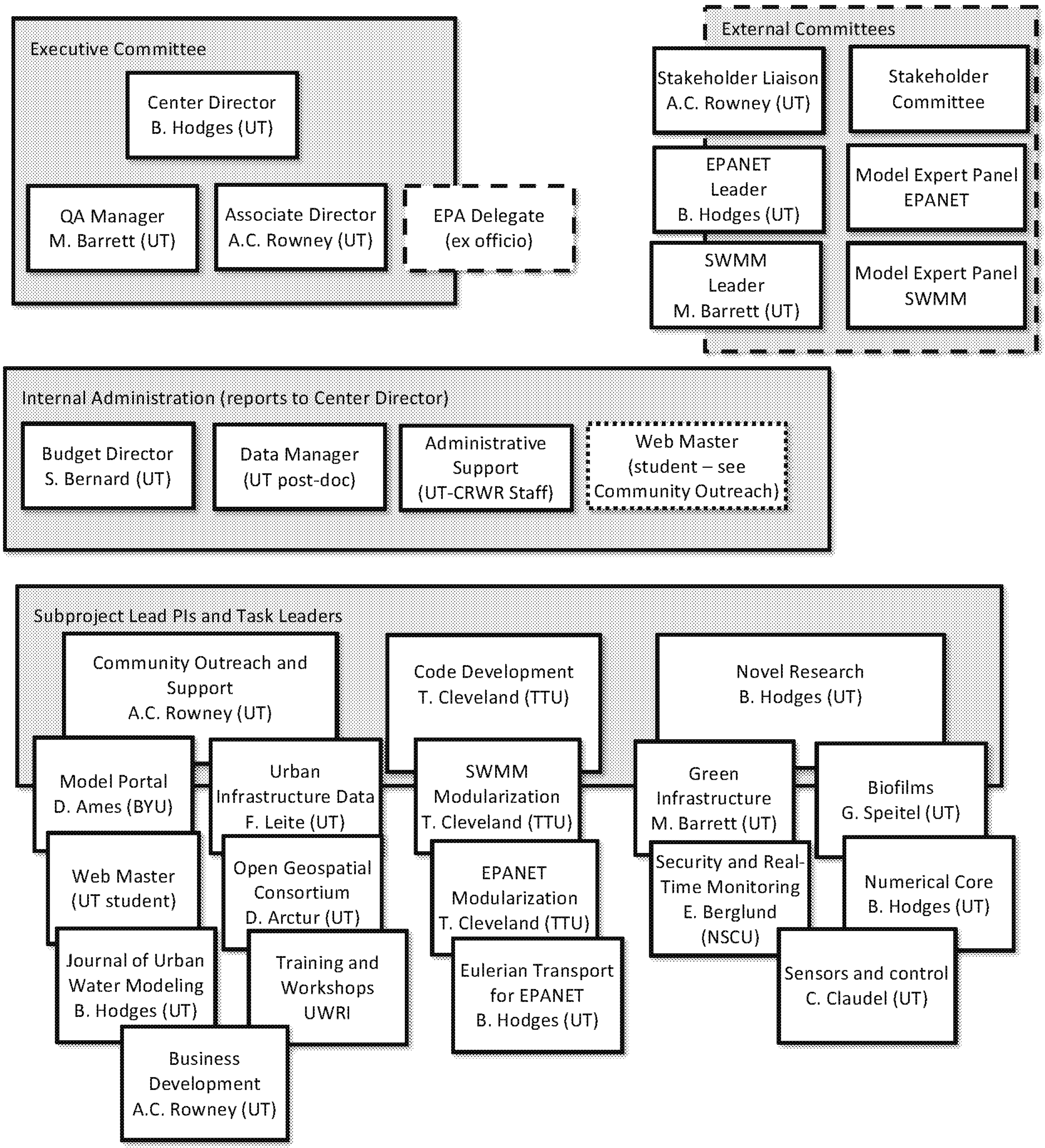


Figure 10-1. Organization of National Center of Sustainable Water Infrastructure Modeling.

The key external responsibilities for Center Staff are outlined in the box at right. These personnel have routine responsibilities work with external communities of interest relative to the Center administration (see Section 6A: Community Outreach and Support, pg 10).

Key External Responsibilities of Center Staff

Center Director – Provides liaison to EPA Project Officer. Works with all external committees/panels

Stakeholder Liaison (Associate Center Director) – Keeps in touch with the needs of the community through the Stakeholder Committee (§ 7.2) and works with SWMM and EPANET Leaders to ensure the subprojects are getting consistent guidance on the direction for the Center.

SWMM Leader – Provides liaison between the SWMM Model Expert Panel (§ 7.3) and the Lead PIs and Task Leaders working on SWMM model projects

EPANET Leader – Provides liaison between the EPANET Model Expert Panel (§ 7.3) and the Lead PIs and Task Leaders working on EPANET model projects

2 Research coordination, communication, and integration of schedules

2.1 The Model Portal as a communication and project integration tool

Key to research integration is the Model Portal (see Section 6A: Community Outreach and Support, pg 10). The Model Portal provides a central repository for communicating results to the broader community and within the Center itself. As new model code and documents are written and go through the QA process (see Section 7: Quality Management Plan, pg 55) other project participants will be able to see, use, and comment on the code and documents.

2.2 Research coordination and communication

Research coordination and integration of schedules/project milestones will be critical to the Center operation. Several of the modeling projects are interdependent. For example, the Biofilms task in the Novel Research subproject requires the Eulerian Transport algorithms and sub-segmenting of EPANET to be completed before the Biofilms Module can be completely tested. However, we can work on these project concurrently with the Model Portal as a communications path. The Biofilms task personnel will have an early look at the Eulerian Transport code, and can provide feedback on the biofilm needs as their models are developed.

Research coordination will include:

1. Bimonthly teleconference meetings of all PIs and Task Leaders. Those who cannot attend the call must provide a short summary of progress to be distributed.
2. Semi-annual meeting of Executive Committee and Lead PIs on subprojects. Meeting in-person is preferred, but may include video conferences if scheduling/costs become an issue.
3. Online project tracking, milestones, and report summaries.
4. Web site that provides up-to-date information on draft and final project reports, community comments.

3 Funding Decisions and Priorities

3.1 Where the buck stops

Funding decisions and priorities for the Center will be set by the Executive Committee, after consultation with the external Stakeholder Committee, Model Expert Panels, and EPA. Final responsibility for funding decisions, executing the funding distribution, and financial oversight will reside with the Center Director.

3.2 External funding, business development, and collaboration with industry

We have not formalized letters of intent/collaboration with industry partners at this time. Wherever the Center is established there will be a wide range of national and international vendors, engineering firms and multinational information technology corporations and academics that will be interested in working with the Center. It is in the Center and EPA's interest to have collaboration discussions in an open and competitive framework after award of the Center rather than in closed partnership arrangements decided during the proposal phase. Our research team is committed to establishing a truly national and long-term Center that is open to work with all industry, government agencies, and academics – including those who are in competing proposals.

We believe that the Center needs to be continuously and actively reaching out beyond the core partners who are submitting this proposal. To this end, we have set aside $105,000 over the 5 year project as unallocated subawards, which will be used to (i) issue RFPs to bring in outside experts for specific tasks, (ii) engage new academic/industry partners in the project, (iii) provide honorariums to external individuals for providing the time-consuming peer reviews required by our QA/QC plan, and (iv) buffer unanticipated but bona fide variances in research requirements.

We have a strong business development plan (see Section 6A Outreach and Support, pg 10) that will provide sustainable Center funding through training and support. Furthermore, by building the core modularization of the model (Section 6B Code Development, pg 25) and providing a new, high-speed numerical solver (Section 6C Novel Research, pg 40) we are building the Center's key products into fast, efficient codes to work with industry in a variety of collaborations to provide new services and capabilities.

3.3 Funding and the future of the Center

We recognize that the long-term innovation and improvements needed/desired for water infrastructure models are far beyond the EPA's allocated budget for the Center. Furthermore, innovation in sustainable water infrastructure models depends on innovation in related disciplines, which cannot be directly funded through the Center. For example, the Center can use the existing state-of-the-art in biofilms to (i) develop a modeling package that applies this existing knowledge to EPANET, and (ii) identify critical unknowns that limit the modeling package and therefore deserve further research. However, the Center cannot directly be a source of funding for biofilm research per se. Thus, there are limitations on what the Center can accomplish based on both the evolving state-of-the-science and available funding.

In this proposal, we have outlined our vision of priorities for the Center. However, we recognize that these priorities should be a matter of further consultation with the broader community and EPA. Our goal is to build a sustainable National Center that engages the community in determining priorities, raising research funds, and providing a centralized hub for sharing novel research and code development. As such, we intend to begin with community engagement in year 1 to consider priority works for succeeding years. The budgets for years 2-5 in this project should be considered preliminary, and subject to discussion within the community-based Stakeholder Committee and Model Expert Panels. We want the Center to begin its life with community engagement in focusing long-term priorities, which we believe will ensure a vital and vibrant Center beyond the 5-year EPA funding.

We believe our projects of EPANET and SWMM Modularization and development of the community Model Portal are keys to the future success of the Center by making the models more computationally efficient, robust, and easier to adapt for future innovations. The additional tasks in code development, novel research and outreach in this proposal provide an excellent, achievable path towards increasing model capabilities and community engagement. However, broader community engagement and consultation with the EPA during the first year of the Center might lead to a modified set of priorities. Our Center stands ready with a cadre of researchers with wide expertise that can adapt to the community needs, and we have a flexible organization that can readily bring in additional expertise through our subaward arrangements with UWRI and our ability to engage additional personnel under a Research Affiliate[1] status at the Center for Research in Water Resources at UT Austin.

3.4 The funding cycle for tasks

Once model needs and requirements have been set, developing new model capabilities typically requires 3 layers of work, i.e.:

1. **Review** of state-of-the-art and development of model equations,
2. **Implementation** of model equations within the model,
3. **Testing** and validation of result.

Traditionally, all 3 layers of innovation have been conducted by a single investigator or team. We propose to engage the community throughout the funding cycle for in an innovative 5-step process (see box on next page)

Funding for the external RFPs in the model development plan (see box) will be initially from the Center's EPA budget, where $105K of subawards is presently unallocated. In later years the Center will rely on support from external sources.

4 Expense programmatic control

Funding for individual PIs in years 2-5 in this project are considered provisional and depend upon the evolving focus of the Center (based on EPA and community input) as well as year-to-year performance of the PIs.

The Center will generally provide external Lead PIs and subaward Task Leaders with funding for a single year for a discrete project. External project renewal will depend on performance based on QA/QC deliverables (see Section 7: Quality Management Plan, pg 55) as overseen by the Executive Committee, with final decisions by the Center Director.

[1] Note that the Center Associate Director, Dr. A.C. Rowney, has been engaged under a Research Fellow status at CRWR UT Austin to provide closer linkage between the Center and UWRI.

The Center funding at UT will not be distributed to individual PIs or senior personnel, but will be controlled year-to-year by the Center Director in consultation with the Executive Committee based on project needs and performance to QA/QC deliverables.

Travel expenses for workshop participants and Center personnel will generally be controlled by the Center Director. The exception will be external subawards that contain line-items for travel, workshops or training – which will primarily be those conducted by UWRI using professionals from the broader community (see Section 6A: Community Outreach and Support).

Delays in performance and expending research funds are common in academia when projects depend on recruiting new students to perform tasks. However, we envision this to be a minor issue for the Center as many of the tasks require the expertise and direct work of PIs and/or post-docs. The Lead PIs and Task Leaders identified in this project are all "hands on" scientists who expect to put significant time and effort directly into the model development. In particular, the initial stages of most tasks require PIs to study the needs, requirements, and theory for implementing new capabilities, which cannot be reasonably performed by students.

A 5-step Approach for Distributing and Monitoring New Funding for New Model Capabilities

1. The Model Expert Panel (with input from Stakeholder Committee) prioritizes ideas for improving models.

2. The Executive Committee and Stakeholder Committee examines whether the determining community needs, state-of-the-art theory, and algorithms for the priority model improvement should be undertaken by the Center's PIs or through an external grant to the broader community to create a Technical Report.

3. For external awards, the Center creates, releases, and selects winning respondent(s) of an external RFP focused on a review of the state-of-the-art and developing model equations for the improvement. The selected external awardee will be expected to work with the Model Expert Panel, and the Community Outreach project of the Center.

4. The Center and the Model Expert Panel will consider the completed state-of-the-art review and decide on one of four possible approaches:

   a. Do not move forward (i.e. the state-of-the-art is not recommended for implementation at this time),

   b. Create an RFP to add the new capability to the model(s) using an external award,

   c. Select one of the Center's Lead PIs or Senior Person to conduct the work,

   d. Organize a "hack-a-thon" with a cash prize to the person or team that writes the best code.

5. The Center will develop a plan for testing, tracking progress, and evaluation of the new code. This effort may include additional external competitions or collaborations with federal, state, or local water agencies interested in the model. For further details on tracking and validation of projects, see Section 7: Quality Management Plan.

5 Quality Assurance responsibilities and decisions

The Quality Assurance Manager will hold direct administrative responsibility for QA/QC, and will oversee the submittal of deliverables from Lead PIs. Lead PIs will be responsible for deliverables from the Task Leaders in their projects, and will call on the QA Manager for assistance. The QA Manager will oversee whether deliverables meet the basic standards of the QA plan. Technical Quality Control for scientific content of deliverables will be responsibility of the immediate Task Leader, followed by the Lead PI and the Model Expert Panel, with assistance of the QA Manager and the Executive Committee. Further details are provided in Section 7 Quality Management Plan (pg 55).

6 Metrics of project success and progress

The Center's performance can be judged by different metrics for Community Outreach, Community Support, Code Development, and Novel Research. In general, these metrics will be able to be evaluated on a quarterly or semi-annual basis. The Center Director and Internal Administrative Staff will work with the Lead PIs to collect these metrics. The Executive Committee and Stakeholder Committee will review available metrics on a quarterly basis. We will discuss with the EPA project officer allowable options for collecting user feedback within the requirements of the Federal Paperwork Reduction Act.

6.1 Metrics for Community Outreach:

The success of Community Outreach will be measured by the number of people engaged with the Center (outside of funded entities) and through feedback comments on Community Outreach solicited in online forums, the Model Portal, and in training sessions. Analysis of feedback will be used to improve the Center's operations. The following are representative metrics of numerical impact and quality of impact:

- The number of community comments that have been provided.
- The number of community programmers that have contributed model features/bug fixes.
- The number of community users that have contributed test cases to the Case Library.
- The number of papers being submitted to the Journal of Water Infrastructure Modeling.
- The percentage of positive feedback comments on Community Outreach.
- The percentage of negative feedback comments on Community Outreach.
- The percentage of feedback comments on Community Outreach providing constructive criticism leading to Center improvements.
- The percentage of community-contributed features/bug fixes that have been downloaded.
- The percentage of community-contributed test cases that have been downloaded.

6.2 Metrics for Community Support

The overall impact of the Community Support will be measured by the number of people involved in the training, using the models, and seeking the Center's support. The quality of the support and program success will be based on feedback from the community users who download code, documents, and participate in the Case Library and GitHub through the Model Portal. Analysis of feedback will be used to improve the Center's operations. The following are representative metrics of numerical impact and quality of impact:

- The number of training sessions that have been offered.
- The number of people that have been trained on the models.
- The number of online questions on models that have been asked and answered.
- The number of online questions that have been satisfactorily resolved.
- The number of people that have downloaded User Manuals.
- The number of modelers that have downloaded the codes.
- The number of programmers that have forked the code on GitHub.
- The percentage of positive feedback comments on Community Support.
- The percentage of negative feedback comments on Community Support.
- The percentage of feedback comments on Community Support providing constructive criticism leading to Center improvements.

6.3 Metrics for Code Development

Each Code Development project will have metrics for success that are agreed on by the Task Leader, Lead PI, and the Center Director. These will depend on the nature of the project, but will include (at a minimum):

- The coding project is meeting the agreed timeline.
- Problems and/or delays are being promptly reported to Lead PI and Executive Committee.
- The Model Expert Panel is being consulted on problems and questions.
- The Community Outreach program (Model Portal) is being used to engage the community in resolving coding issues.
- The Method of Manufactured Solutions (Roache, 2002) has been successfully run on the individual code modules.
- The coding is meeting the Quality Assurance Project Plan milestones and passing Quality Control checks.
- The user and programmer documentation is keeping pace with the code development.
- At completion of coding phase: the code passes the initial validation tests.
- After completion of validation phase: the code passes the full case study validation tests.

- After completion of validation phase: the documents and code are fully available on the Model Portal.
- As a follow up after completion: quantify use of the new model and community positive/negative feedback.

6.4 Metrics for Novel Research

The fundamental metrics for Novel Research will be completion of theory and code modules that incorporate Novel Research topics. The Novel Research metrics will include

- The Novel Research produced a workable theory.
- Coding for Novel Research – see description of Code Development metrics above.
- The research been presented at a conference or workshop.
- The research has been published in a paper or technical note?
- Students working on the project graduated.
- Post-doc graduates working on the project found jobs in their field.

6.5 Application of Metrics

Although the above metrics are a useful compilation of indicators for the various categories they represent, they cannot be usefully applied individually. To do so almost inevitably leads to a narrative evaluation which acknowledges but does not truly apply the metrics, and also to an inability to track performance shifts over time (e.g. QC lapses) or between functionally equivalent entities (e.g. two project managers). There is a formal mathematics associated with index development and aggregation to surmount these kinds of issues, and we are experienced in their application. Given the nature of this problem, some of the metrics will emerge over different time scales (e.g. numbers who 'found jobs in their field' will take years to determine, while coding 'meeting the agreed timeline' will be rapidly determined at any moment but continuously variable). Further, some will be 'hard' determinations (e.g. an expenditure number) while others will be 'soft' (e.g. whether a job is in one's field can be arguable). The process by which we will approach this is a proven pattern of numerical resolution and stakeholder preference ranking. i) All metrics will be confirmed with stakeholders as valid and reasonable. (ii) All metrics will be converted to indices of consistent scale direction, i.e. increasing or decreasing as appropriate. iii) All indices will be transformed to common scale magnitudes (to avoid eclipsing). iv) All indices will be assigned a weighting value based on stakeholder preferences so the relative value of each index in the total aggregate value is appropriate. v) Indices will be aggregated so that performance shifts are balanced and not abrupt (e.g. 'brittle'), vi) Aggregate indices will be developed for a range of cases, and vetted by stakeholders. In application, it may prove to be useful to employ uncertainty components to the aggregation. It is proposed that this be deferred until need is shown.

Approached this way, there will be confidence that comparisons over time or between entities will be well founded. In each case, values developed for each underlying metric will be assigned as a normal element of project accounting, and will be audited annually to verify validity.

7 Committees and Panels

7.1 Executive Committee

The Executive Committee (Figure 10-1) is comprised of the Center Director, Associate Director, and QA Manager, with the EPA Program Officer participating in an *ex officio* capacity (non-voting observer). The Executive Committee will have a monthly meeting (in person or video teleconference) where they will consider progress, issues, and the Center's direction. The Executive Committee will work closely with the Stakeholder Committee and the Model Expert Panels to ensure that the Center is meeting the needs of the model user/developer communities. The Executive Committee will set the direction and priorities of the Center, to be carried out by the Center Director and the Lead PIs.

7.2 Stakeholder Committee

7.2.1 Overview

The Stakeholder Committee will be composed of experts in water infrastructure model development and application from industry, academia, and state/local agencies. Experts from federal agencies will be invited to participate as *ex-officio* (observer, non-voting) committee members. Our goal is to obtain a diverse committee whose combined experience in stormwater and water distribution systems covers a wide range of real-world experience.

7.2.2 The Raison d'être for the Stakeholder Committee

The Stakeholder Panel will help the Center keep the long-term needs of the community in focus by providing ready access to experts with a history of working in water infrastructure modeling.

7.2.3 Charge to the Stakeholder Committee

The Stakeholder Committee will:

- Prioritize needs for model innovation (in concert with Model Expert Panels).
- Provide advice and guidance to the Executive Committee.
- Work with Executive Committee in raising research funds to enable long-term Center operation.

The Associate Director will work closely with the Stakeholder Committee and keep them apprised of important issues/questions as they arise.

The Stakeholder Committee will initially meet on a quarterly, then semi-annual, and finally on an annual basis. We expect that more frequent meetings in the first and second years will be necessary to ensure that the Center's evolves in the most effective directions. The Executive Committee and Stakeholder Committee may arrange for more frequent meetings, if necessary.

7.2.4 Membership in the Stakeholder Committee

The Stakeholder Committee will likely be 8 to 12 external experts, and will include one or more representatives of the EPA in *ex officio* capacity (observer, non-voting). Membership on the Stakeholder Committee should be relatively stable over time. We would like to have committee members agree to serve at least 3 years. Once the committee is established, we will discuss arrangements for a regular, but staged, turnover in membership. We would like to see members serving no more than 3 terms, with 1 or 2 new members being replaced each year.

7.3 Model Expert Panels

7.3.1 Overview

The Center will organize and support a SWMM Model Expert Panel and a separate EPANET Model Expert Panel to act as steering committees to guide the model development. These are designated as panels rather than committees as we are expecting the membership of the panel to be fluid, depending on the questions of interest.

7.3.2 Charge to the Model Expert Panels

The Model Expert Panel will:

- Prioritize needs for model innovation (in concert with Stakeholder Committee).
- Select experts for white papers/review/workshops on new model features.
- Negotiate with Center Director to set honorarium levels for reviewers.
- Formulate RFP/RFQ for model advances.
- Oversee proposal reviews to disburse the Center's external innovation funds.
- Review QA Project Plan, QA deliverables, and QC reports.

7.3.3 Overview of Model Expert Panel operations

A portion of the Center budget will be targeted for external competitive innovation. The Center will work towards leveraging these funds with external (non-EPA) support. The goal will be to develop a long-term approach for sustaining innovation without expectation of routine injection of EPA funds. The Expert Panel will maintain an online matrix of innovation needs and the state-of-the art. This table will also provide academic communities a framework and motivation for disciplinary work that can be funded by other agencies.

Academic communities of interest will be engaged to provide feedback to the Model Expert Panels. We see this as a way academic researchers can help fulfill their broader impacts and outreach goals under other disciplinary funding and make their work available to the practicing community.

Expert Panels will oversee a staged innovation process that includes

1. Development of a technical report (white paper) on a proposed new model feature.
2. Review of the white paper.
3. Community workshop to discuss white paper, reviews, and define a research program.
4. Commission a coding project.
5. Review/approval of code and documentation.
6. Commission validation project.
7. Review/approval of validation test case and results.

Each of the above steps will be conducted by experts from the Center or the broader modeling community, as selected by the panel through either RFQ or RFP processes. Where appropriate, the Model Expert Panel and the Center Director will offer honorariums for participation in reviews or workshops that require extensive time commitments of outside experts. Further details on the Model Expert Panel operations are provided in the box on the next page.

Detailed Operation of Model Expert Panel Duties

Development of white paper: A group of experts (2 or 3) will be tasked to develop a technical report (white paper) that sets out the algorithms and model developments required to add state-of-the-art capabilities to the models. This will typically be a 6 month to 1 year project that might be directed to a Center expert or through an RFP/RFQ process to external experts (see § 3 above).

Review of white paper: The recommendations in the white paper will be peer reviewed by a team of experts including EPA, government laboratories, academics, and practitioners. The experts will be selected by the Panel and compensated (where allowed) by an honorarium. Travel expenses for the experts to meet and to confer will be covered by the Center, if funds are available.

Community Workshop: The white paper and expert reviews will be presented to the community and a workshop will be organized to discuss the results. The focus of the workshop will be on defining the research path forward and reaching a consensus as to whether the proposed model improvements are desirable, practical, and worth the potential development costs. If sufficient funding is available, the key experts in the field may be provided with travel expenses and honorariums.

Coding Project: The Panel will commission and oversee an external RFP/RFQ or internal award to add model improvements. Where code additions can be broken into small modules, the Panel may decide to use a "Hack-a-thon" approach with a monetary prize for the best code delivered in some time period. Code will be delivered with documentation and with a test case that will be archived in the Case Library (see Section 6A: Community Outreach and Support)

Project Review/Acceptance: The Panel will be responsible for review and acceptance of code and documentation delivered under a Coding Project (see Section 7: Quality Management Plan). This review will be to ensure that the code and documentation meet the standards of the Center for inclusion in the models. The Panel may decide to complete this review itself, or commission external/internal reviewers. External reviewers may be compensated with an honorarium (where allowable).

Validation Project: The Panel will commission and oversee (internal or external) one or more experts to test and validate the model. This will generally require producing a data set separate from that used by the Coding Project for developing and demonstrating the new model features. The Validation Project will test and revise both the code and user documentation, as necessary. The Validation Project will be delivered with documentation and a test case that will be archived in the Case Library (see Section 6A: Community Outreach and Support)

Validation Review/Acceptance: The Innovation Panel will be responsible for review and acceptance of deliverables from a Validation Project. This review will be to ensure that any revised code, documentation, and test cases meet the standards of the Center for inclusion in the models, the Case Library, and the Document Library. The Panel may decide to complete this review itself, or commission external/internal reviewers. External reviewers may be compensated with an honorarium (where allowable).

7.3.4 *Raison d'être for the Model Expert Panels*

The Center has designated several key areas for novel research (see Novel Research Subproject Description), but there is a need for developing an ongoing framework to establish community consensus for future improvements.

As the core EPA funding ends, there is a need for an established community panel to oversee model improvements and provide and established path for community-supported QA/QC of new model innovations.

7.3.5 *Membership in the Model Experts Panel*

The Model Expert Panels will be drawn from model user and programmer communities, experts from the Center, and *ex officio* (non-voting, observer) delegates from the EPA. Membership will be selected by the Executive Committee and the Stakeholder Committee. Rather than a standing committee (e.g. such as the Stakeholder Committee), the Model Expert Panel composition may alter periodically depending on the questions at hand. The Center Director, Associate Director and QA Manager will be members of both SWMM and EPANET panels. It is expected that the Model Expert panels will typically include 4 to 6 external members.

8 Dissemination of research

8.1 Overview

Public and professional dissemination of research results, findings, information, and code will be made through the Model Portal, a website (including a blog), Twitter, press releases, workshops, training, conferences, technical reports, and journal publications. For information on the Model Portal, and training, see Section 6A: Community Outreach and Support (pg 10). For other dissemination avenues, see below.

8.2 Publicity: Website, Blogging, Twitter, and Press Releases

We recognize that science and engineering must be continually reaching out to the public to let them know how their tax dollars are being spent and what benefits they can see. To this end, we will work with formal press releases and a Center website, including real-time blogs and Twitter connections to engage both the public and other researchers in our work.

Center Website

The Center website will be hosted at the Center for Research in Water Resources (CRWR) at UT Austin. The website will be initially built with the assistance of CRWR staff, and maintained by a graduate student as a part-time duty (see Figure 10-1). The PI Hodges has had extensive experience in keeping up a long-term web site that includes a blog and Twitter connections (see http://www.crwr.utexas.edu/hodges). The Center website will be a public face of the Center that is written and maintained for outreach beyond the users and programmers, who will be directed towards the Model Portal website.

Blogging and Twitter

We believe that blogging and Twitter can be an extremely effective approach to engaging the public. Presently, PI Hodges runs a blog that provides short pieces of ongoing research (http://www.crwr.utexas.edu/hodges/blog) and is active on Twitter (@BenHodgesH20). Our goal is to make blogging and Twitter easy for the research team, so that co-PIs, Task Leaders, post-docs, and students can all get involved. Because this is an issue that greatly interests PI Hodges, he will take on the role of editor and encourager-in-chief for blogging and Twitter for the Center.

Press Releases

We will work with the public communications team in the Cockrell School of Engineering and Civil, Architectural and Environmental Engineering Department to produce press releases (see http://www.engr.utexas.edu/news http://www.caee.utexas.edu/news/features). PI Hodges' has experience in developing a public face for research. His work on developing river network models with IBM has received extensive publicity, including a recent local TV spot (see http://www.crwr.utexas.edu/hodges/blog/in-the-news.html), write-ups in *Civil Engineering* magazine (Landers 2011), and was feature in a workshop with U.S Congressmen and staff arranged by IBM.

8.3 Professional Dissemination

Technical Reports

Documenting code development for both users and programmers in technical reports will be an integral part of each project in the Center. Technical reports will go through the QA/QC process outlined in Section 7: Quality Management Plan. All technical reports will be electronic documents that will be indexed and searchable through the Center Website. Long term archiving will be through the University of Texas Digital Repository (UTDR), see Section 9 Data Plan (pg 61).

Conferences and Workshops

The Center will arrange for students, post-docs and PIs to present research findings at national and international conferences. We will actively lead special sessions at major conferences (e.g. at the annual EWRI World Environmental & Water Resources Conference). We will arrange regular workshops at UT Austin to keep the professional community engaged in our work.

Journal Publications

Post-docs, graduate students, and PIs will be expected to publish research findings in peer-reviewed journals. As discussed in Section 6A Community Outreach and Support (pg 10), we will establish a new *Journal of Water Infrastructure Modeling* that will broaden our ability to publish model code results and testing. It is our belief that present journals do not serve the model development community, where writing and testing code are vital tasks that must be documented and repeatable. The new journal will be organized to encourage a greater breadth of material to be published from the Center's work.

8.4 Internal information flow among investigators

Internal information flow among investigators will be supported by the Model Portal, for details see Section 6A Community Outreach and Support (pg 10). As a brief overview, the Model Portal makes all coding work within the Center immediately open to the public, as will be documents as they are under development. This open-source approach to both the code and the documentation will allow other investigators to readily see what is happening in other projects. The research integration meetings discussed above in §2 will allow the Center Director and PIs to ensure that adequate information is moving between the different subprojects and tasks.

9 Administrative Staff

The Center will rely on the administrative staff of the Center for Research in Water Resources (CRWR) at the University of Texas at Austin. This staff consists of Ms. Sharon Bernard, Mr. Michael Godwin, Ms. RoseAnna Goewey, and Ms. Kris Powledge. They have extensive experience in handling budgeting, appointments, travel, arranging workshops, purchasing, and working within State of Texas and Federal regulations. Ms. Bernard is the CRWR office manager who apportions tasks to the staff.

Ms. Sharon Bernard will act as Budget Director to assist PI Hodges and the Executive Committee in financial organization. She has more than 20 years of experience in budgeting and financial work for Federal research projects with the Center for Research in Water Resources and the UT Office of Sponsored Projects. The administrative budget in this proposal reflects 2.2 Full-time equivalent (FTE) person-months per year for direct staff support on Center tasks that are directly chargeable under Federal regulations. The staff support for normal, indirectly-charged tasks will be funded out of return-of-overhead from the Cockrell School of Engineering to CRWR.

Data management (see Section 9 Data Plan, pg 61) will be overseen as a part time (~10%) duty of a post-doctoral scientist who is otherwise employed in the Code Development and/or Novel Research projects. The Data Manager will have the assistance of computer support staff from CRWR with a 0.6 FTE allocation in the budget.

Section 11: References

Ames, D.P., Horsburgh, J.S., Cao, Y., Kadlec, J., Whiteaker, T., and Valentine, D., (2012). HydroDesktop: Web Services-Based Software for Hydrologic Data Discovery, Download, Visualization, and Analysis. *Environmental Modelling & Software*. Vol 37, pp 146-156.

Ames et al (2008); "MapWindow Open Source GIS Team," Available at http://www.mapwindow.org/apps/team. Last access: October 13, 2014.

Barrett, M., et al., 2012, *Linking BMP Systems Performance to Receiving Water Protection: BMP Performance Algorithms*, Water Environment Research Foundation, Alexandria, VA

Begel, A., J. Bosch, and M.-A Storey (2013), "Social networking meets software development," *IEEE Software*, 13:1:52-66.

Bird, C., Alex Gourley, and Prem Devanbu. (2007). Detecting Patch Submission and Acceptance in OSS Projects. In Proceedings of the Fourth International Workshop on Mining Software Repositories (MSR '07). IEEE Computer Society, Washington, DC, USA

Boesen, M. R., Madsen, J., and Keymeulen, D., (2011). "Autonomous Distributed Self-organizing and Self-healing Hardware Architecture, The eDNA concept", Aero-space Conference, IEEE.

Brownell, H.G. (1895). "The Wheatstone Bridge." The Electrical Journal 1:2:28-29.

BuildingSmart (2014a). "BuildingSmart". Available at: http://www.buildingsmart.org. Last access: October 10, 2014.

BuildingSmart (2014b). "Summary of IFC Releases". Available at: http://www.buildingsmart-tech.org/specifications/ifc-releases. Last access: October 10, 2014.

Cheung, C.M.K., and M.K.O. Lee (2010). "Understanding the sustainability of a virtual community: model development and empirical test," *Journal of Information Science*, 35:3:279-298.

Cleveland, T.G., and Botkins, W. (2008). ``Hypothetical Watershed Modeling - Block B." Harris County Flood Control District, Research Report in Support of the Floodwise Block-B Study. (http://www.rtfmps.com/resumes/MyWebPapers/project_reports/SWMM_hypothetical/2008_1102_SWMM_Hypothetical.pdf)

Crowston, K., and J. Howison (2005). The social structure of free and open source software development. First Monday, 10(2).

Fowler, Martin (with contributions by Kent Beck, John Brant, William Opdyke, and Don Roberts) (1999). Refactoring: Improving the Design of Existing Code. Addison-Wesley, David, O., J.C. Ascough II, W. Lloyd, T.R. Green, K.W. Rojas, G.H. Leavesley, and L.R. Ahuja (2013), "A software engineering perspective on environmental modeling framework design: The Object Modeling System," *Environmental Modelling & Software,* 39:201-213.

George, A. and J. W-H Liu (1981). *Computer Solution of Large Sparse Positive Definite Systems*, Prentice-Hall

Grinter, R. E. (1995). "Using a configuration management tool to coordinate software development." *Proceedings of a conference on Organizational Computing Systems*, Milpitas, CA. pp 168-177, ACM.

Grinter, R. E. (1999). System architecture: Product designing and social engineering. work activities coordination and collaboration. ACM: San Francisco.

GSA (2014) General Services Administration. "3D-4D Building Information Modeling". Available at: http://www.gsa.gov/bim. Last access: October 10, 2014.

Guillaume, J.H.A. (2011), "A risk-based tool for documenting and auditing the modelling process," 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011. pp. 3854 – 3860. http://mssanz.org.au/modsim2011

Hansson, H., Akerholm, M., Crnkovic, I., and Torngren, M., (2004). "SaveCCM – a Component Model for Safety-Critical Real-Time Systems". In Proceedings of 30 Euromicro Conference, Special Session Component Models for Dependable Systems.

Hodges, B.R., and F. Liu (2014a), *Rivers and electrical networks: Crossing disciplines in modeling and simulation*, Now Publishers Inc. 134 pgs. ISBN: 978-1601987723. Available at http://amzn.to/1qcujU3

Hodges, B.R. and F. Liu (2014b). "River modeling – keeping it physical for river basins." in eds. M. Toffolon and S. Piccolroz, *Proceedings of the 17th Workshop on Physical Processes in Natural Waters (PPNW2014)*, Trento (Italy), July 1-4, 2014. pp. 44-45. http://eprints.biblio.unitn.it/4293/

Hodges, B.R. (2014), "A new approach to the local time stepping problem for scalar transport," *Ocean Modelling*, 77:1-19. http://dx.doi.org/10.1016/j.ocemod.2014.02.007

Hodges, B.R. and F.J. Rueda (2008), "Semi-implicit two-level predictor-corrector methods for non-linearly coupled, hydrostatic, barotropic/baroclinic flows," *International Journal of Computational Fluid Dynamics*, 22:9:593-607. DOI: 10.1080/10618560802353389

Hou, X. and B.R. Hodges (2014), "Integrating Google Maps/Earth in an automated oil spill forecast system," *Marine Technology Society Journal*, 48:4:79-85.

Howison, J., K. Inoue, and K. Crowston (2009). "Social dynamics of free and open source team communications." International Federation for Information Processing Digital Library, 203(1), .

Joshi, P. (2002). *Web-Based Re-Engineering of Dynamic Lake Water Quality Modeling Software, MINLAKE.* M.S. Thesis, Department of Civil and Environmental Engineering, University of Houston.

Knupp, P., & Salari, K., (2010). *Verification of computer codes in computational science and engineering*. CRC Press.

Landers, J. (2011) "Hydrologic Model Could Improve River Simulation, Flood Prediction Capabilities", *Civil Engineering,* Nov 2011, pp 38-39,

Liu, F. and B.R. Hodges (2012), "Dynamic River Network Simulation at Large Scale," *Proceedings of the 49th ACM/EDAC/IEEE Design Automation Conference*, June 3-7, 2012, San Francisco USA, pp. 723-728.

Liu, F. and B.R. Hodges, (2014a) "Applying microprocessor analysis methods to river network modeling," *Environmental Modelling & Software*. 52:234-252. http://dx.doi.org/10.1016/j.envsoft.2013.09.013

Liu, F. and B.R. Hodges (2014b), "Integrating an open source dynamic river model in hydrology modeling frameworks," *Geophysical Research Abstracts*, Vol. 16, EGU2014-15822, presented at the European Geosciences Union General Assembly, Vienna, Austria, April 27-May 2, 2014.

Magge, J., Georgiadis, I., and Kramer, J. (2002), "Self-organizing software architectures for distributed systems", In WOSS'02, 2002.

Maloney, John; Hernández, Andrés; Rusk, Natalie; Eastmond, Evelyn; Brennan, Karen; Millner, Amon; Rosenbaum, Eric; Silver, Jay; Silverman, Brian; Kafai, Yasmin (November 2009). "Scratch: Programming for All". Communications of the ACM 52 (11): 60–67. (http://scratch.mit.edu/)

Oberkampf, W.L., F.G. Blottner, (1998). " Issues in Computational Fluid Dynamics: Code Verification and Validation," *AIAA Journal*, Vol. 36, No. 5, pp. 687-695.

OGC (2014a) Open Geospatial Consortium. "About OGC". Available at: http://www.opengeospatial.org/ogc. Last access: October 10, 2014.

OGC (2014b) Open Geospatial Consortium. "OGC Reference Model (ORM)". Available at: http://www.opengeospatial.org/standards/orm. Last access: October 10, 2014.

OGC (2014c) Open Geospatial Consortium. "Urban Planning DWG". Available at: http://www.opengeospatial.org/projects/groups/urbanplanning Last access: October 13, 2014.

OGC (2014d) Open Geospatial Consortium. "PipelineML SWG". Available at: http://www.opengeospatial.org/projects/groups/pipemlswg Last access: October 13, 2014.

OGC (2014e) Open Geospatial Consortium. "Land-Infrastructure DWG". Available at: http://www.opengeospatial.org/projects/groups/landinfradwg Last access: October 13, 2014.

Okon, S. C. (2006), “A Fail-safe Strategy for Scientific/Engineering Project: A Tool for Sustainable Development”, Journal of Sciences and Technology Research Vol. 5 No. 2, pp 6-9,

Okon, S. C., and Asagba, P. O., (2013). “Deploying Self-organizing-healing Techniques for Software Development of Iterative Linear Solver”. International Journal of Computational Engineering Research, vol 3 no 2.

R Team (2008) R Development Core Team. “R: A Language and Environment for Statistical Computing.” R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0 (URL: http://cran.us.r-project.org/).

Reichert, P. (1998). *AQUASIM 2.0 – User Manual.* Swiss Federal Institute for Environmental Science and Technology (EAWAG).

Roache, P.J. (1998). “Verification of Codes and calculations,” *AIAA Journal*, Vol. 36, pp. 696-702

Roache, P.J. (2002), “Code Verification by the Method of Manufactured Solutions,” *Journal of Fluids Engineering*, 124:4-10.

Salari, K., Knupp, P., 2000. Code Verification by the Method of Manufactured Solutions, Sandia Report, Sandia National Laboratories.

Shang, F., J.G. Uber, and L.A. Rossman (2008). EPANET Multi-species extension user’s manual. Technical Report EPA/600/S-07/021, U.S. Environmental Protection Agency, 111 pgs.

Thung, F., T.F. Bissyandé, D. Lo, and L. Jiang (2013), “Network structure of social coding in GitHub,” *Proceedings of the 17th European Conference on Software Maintenance and Reeengineering*, pp. 323-326. http://dx.doi.org/10.1109/CSMR.2013.41

Todini E. & Pilati S. (1988). A gradient algorithm for the analysis of pipe networks. In B. Coulbeck and C.H. Orr (eds) *Computer Applications in Water Supply*, Volume 1 (System analysis and simulation), John Wiley & Sons, London, pp. 1-20.

USACE (2014) United States Army Corps of Engineers (2014). “BIM Contract Requirements”. Available at: https://cadbim.usace.army.mil/BIMContractRequirements. Last access: October 10, 2014.

Yang, T.-Y.B, D.M. Beazley, P. F. Dubois, G. Furnish, (1996). "Steering Object-oriented Computations with Python", Python Workshop 5, Washington D.C., Nov. 4-5.

Yu, Genong and Liping Di (2014) OGC Testbed 10 Cross Community Interoperatibility (CCI) Hydro Model Interoperability Engineering Report, OGC Technical Report OGC 14-048, 65 pgs. http://www.opengeospatial.net/doc/PER/testbed10/cci-hydro-model

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) UT Budget Yr 1	(2) UT Budget Yr 2	(3) UT Budget Yr 3	(4) UT Budget Yr 4	(5)
a. Personnel	$ 183,589.00	$ 249,506.00	$ 256,991.00	$ 263,225.00	$ 953,311.00
b. Fringe Benefits	55,076.00	74,851.00	77,098.00	78,968.00	285,993.00
c. Travel	0.00	0.00	0.00	0.00	
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	15,200.00	9,100.00	4,400.00	4,400.00	33,100.00
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	336,487.00	330,166.00	319,677.00	248,179.00	1,234,509.00
i. Total Direct Charges (sum of 6a-6h)	590,352.00	663,623.00	658,166.00	594,772.00	$ 2,506,913.00
j. Indirect Charges	198,773.00	196,911.00	197,608.00	202,067.00	$ 795,359.00
k. TOTALS (sum of 6i and 6j)	$ 789,125.00	$ 860,534.00	$ 855,774.00	$ 796,839.00	$ 3,302,272.00
7. Program Income	$ 53,300.00	$ 68,300.00	$ 94,650.00	$ 99,650.00	$ 315,900.00

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY (1)	(2)	(3)	(4)	Total (5)
	UT Budget Yr 1-4 (restatement from pg 1)	UT Budget Yr 5			
a. Personnel	$ 953,311.00	$ 227,299.00	$	$	$ 1,180,610.00
b. Fringe Benefits	285,993.00	68,190.00			354,183.00
c. Travel	0.00	0.00			
d. Equipment	0.00	0.00			
e. Supplies	33,100.00	4,400.00			37,500.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	1,234,509.00	221,263.00			1,455,772.00
i. Total Direct Charges (sum of 6a-6h)	2,506,913.00	521,152.00			$ 3,028,065.00
j. Indirect Charges	795,359.00	176,379.00			$ 971,738.00
k. TOTALS (sum of 6i and 6j)	$ 3,302,272.00	$ 697,531.00	$	$	$ 3,999,803.00
7. Program Income	$ 315,900.00	$ 133,650.00	$	$	$ 449,550.00

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) OUTREACH subproject Yr 1	(2) OUTREACH subproject Yr 2	(3) OUTREACH subproject Yr 3	(4) OUTREACH subproject Yr 4	(5)
a. Personnel	$ 35,174.00	$ 36,230.00	$ 37,316.00	$ 36,960.00	$ 145,680.00
b. Fringe Benefits	10,552.00	10,870.00	11,195.00	11,088.00	43,705.00
c. Travel	0.00	0.00	0.00	0.00	
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	6,400.00	1,300.00	1,300.00	1,300.00	10,300.00
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	225,788.00	223,317.00	223,983.00	213,930.00	887,018.00
i. Total Direct Charges (sum of 6a-6h)	277,914.00	271,717.00	273,794.00	263,278.00	$ 1,086,703.00
j. Indirect Charges	54,321.00	28,909.00	27,616.00	27,361.00	$ 138,207.00
k. TOTALS (sum of 6i and 6j)	$ 332,235.00	$ 300,626.00	$ 301,410.00	$ 290,639.00	$ 1,224,910.00
7. Program Income	$ 53,300.00	$ 68,300.00	$ 94,650.00	$ 99,650.00	$ 315,900.00

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total (5)
	(1) OUTREACH subproject Yr 1-4 (restatement from pg 1)	(2) OUTREACH subproject Yr 5	(3)	(4)	
a. Personnel	$ 145,680.00	$ 38,069.00	$	$	$ 183,749.00
b. Fringe Benefits	43,705.00	11,421.00			55,126.00
c. Travel	0.00	0.00			
d. Equipment	0.00	0.00			
e. Supplies	10,300.00	1,300.00			11,600.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	887,018.00	186,314.00			1,073,332.00
i. Total Direct Charges (sum of 6a-6h)	1,086,703.00	237,104.00			$ 1,323,807.00
j. Indirect Charges	138,207.00	28,155.00			$ 166,362.00
k. TOTALS (sum of 6i and 6j)	$ 1,224,910.00	$ 265,259.00	$	$	$ 1,490,169.00
7. Program Income	$ 315,900.00	$ 133,650.00	$	$	$ 449,550.00

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) RESEARCH subproject Yr 1	(2) RESEARCH subproject Yr 2	(3) RESEARCH subproject Yr 3	(4) RESEARCH subproject Yr 4	(5)
a. Personnel	$ 94,017.00	$ 96,837.00	$ 99,743.00	$ 102,734.00	$ 393,331.00
b. Fringe Benefits	28,205.00	29,052.00	29,923.00	30,820.00	118,000.00
c. Travel	0.00	0.00	0.00	0.00	
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	1,600.00	1,600.00	1,600.00	1,600.00	6,400.00
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	48,063.00	33,050.00	33,650.00	34,100.00	148,863.00
i. Total Direct Charges (sum of 6a-6h)	171,885.00	160,539.00	164,916.00	169,254.00	$ 666,594.00
j. Indirect Charges	87,847.00	81,339.00	83,416.00	85,555.00	$ 338,157.00
k. TOTALS (sum of 6i and 6j)	$ 259,732.00	$ 241,878.00	$ 248,332.00	$ 254,809.00	$ 1,004,751.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total (5)
	(1) RESEARCH subproject Yr 1-4 (restatement from pg 1)	(2) RESEARCH subproject Yr 5	(3)	(4)	
a. Personnel	$ 393,331.00	$ 85,630.00	$	$	$ 478,961.00
b. Fringe Benefits	118,000.00	25,689.00			143,689.00
c. Travel	0.00	0.00			
d. Equipment	0.00	0.00			
e. Supplies	6,400.00	1,600.00			8,000.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	148,863.00	34,800.00			183,663.00
i. Total Direct Charges (sum of 6a-6h)	666,594.00	147,719.00			$ 814,313.00
j. Indirect Charges	338,157.00	73,325.00			$ 411,482.00
k. TOTALS (sum of 6i and 6j)	$ 1,004,751.00	$ 221,044.00	$	$	$ 1,225,795.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) CODE subproject Yr 1	(2) CODE subproject Yr 2	(3) CODE subproject Yr 3	(4) CODE subproject Yr 4	(5)
a. Personnel	$ 24,673.00	$ 87,212.00	$ 89,829.00	$ 92,524.00	$ 294,238.00
b. Fringe Benefits	7,402.00	26,163.00	26,948.00	27,758.00	88,271.00
c. Travel	0.00	0.00	0.00	0.00	
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	5,200.00	5,200.00	500.00	500.00	11,400.00
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	62,636.00	73,799.00	62,044.00	149.00	198,628.00
i. Total Direct Charges (sum of 6a-6h)	99,911.00	192,374.00	179,321.00	120,931.00	$ 592,537.00
j. Indirect Charges	34,251.00	65,216.00	64,502.00	66,430.00	$ 230,399.00
k. TOTALS (sum of 6i and 6j)	$ 134,162.00	$ 257,590.00	$ 243,823.00	$ 187,361.00	$ 822,936.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1)	(2)	(3)	(4)	(5)
	CODE subproject Yr 1-4 (restatement from pg 1)	CODE subproject Yr 5			
a. Personnel	$ 294,238.00	$ 72,789.00	$	$	$ 367,027.00
b. Fringe Benefits	88,271.00	21,837.00			110,108.00
c. Travel	0.00	0.00			
d. Equipment	0.00	0.00			
e. Supplies	11,400.00	500.00			11,900.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	198,628.00	149.00			198,777.00
i. Total Direct Charges (sum of 6a-6h)	592,537.00	95,275.00			$ 687,812.00
j. Indirect Charges	230,399.00	52,319.00			$ 282,718.00
k. TOTALS (sum of 6i and 6j)	$ 822,936.00	$ 147,594.00	$	$	$ 970,530.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) ADMIN subproject Yr 1	(2) ADMIN subproject Yr 2	(3) ADMIN subproject Yr 3	(4) ADMIN subproject Yr 4	(5)
a. Personnel	$ 29,725.00	$ 29,227.00	$ 30,103.00	$ 31,007.00	$ 120,062.00
b. Fringe Benefits	8,918.00	8,768.00	9,031.00	9,303.00	36,020.00
c. Travel	0.00	0.00	0.00	0.00	
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	2,000.00	1,000.00	1,000.00	1,000.00	5,000.00
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	0.00	0.00	0.00	0.00	
i. Total Direct Charges (sum of 6a-6h)	40,643.00	38,995.00	40,134.00	41,310.00	$ 161,082.00
j. Indirect Charges	22,354.00	21,447.00	22,074.00	22,721.00	$ 88,596.00
k. TOTALS (sum of 6i and 6j)	$ 62,997.00	$ 60,442.00	$ 62,208.00	$ 64,031.00	$ 249,678.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total (5)
	(1) ADMIN subproject Yr 1-4 (restatement from pg 1)	(2) ADMIN subproject Yr 5	(3)	(4)	
a. Personnel	$ 120,062.00	$ 30,811.00	$	$	$ 150,873.00
b. Fringe Benefits	36,020.00	9,243.00			45,263.00
c. Travel	0.00	0.00			
d. Equipment	0.00	0.00			
e. Supplies	5,000.00	1,000.00			6,000.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	0.00	0.00			
i. Total Direct Charges (sum of 6a-6h)	161,082.00	41,054.00			$ 202,136.00
j. Indirect Charges	88,596.00	22,580.00			$ 111,176.00
k. TOTALS (sum of 6i and 6j)	$ 249,678.00	$ 63,634.00	$	$	$ 313,312.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) BYU Subaward Yr 1	(2) BYU Subaward Yr 2	(3) BYU Subaward Yr 3	(4) BYU Subaward Yr 4	(5)
a. Personnel	$ 12,000.00	$ 15,000.00	$ 15,000.00	$ 9,000.00	$ 51,000.00
b. Fringe Benefits	1,634.00	1,691.00	1,691.00	173.00	5,189.00
c. Travel	0.00	0.00	0.00	0.00	
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	525.00	325.00	0.00	0.00	850.00
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	0.00	6,700.00	6,900.00	3,900.00	17,500.00
i. Total Direct Charges (sum of 6a-6h)	14,159.00	23,716.00	23,591.00	13,073.00	$ 74,539.00
j. Indirect Charges	7,080.00	8,508.00	8,346.00	4,787.00	$ 28,721.00
k. TOTALS (sum of 6i and 6j)	$ 21,239.00	$ 32,224.00	$ 31,937.00	$ 17,860.00	$ 103,260.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1)	(2)	(3)	(4)	(5)
	BYU Subaward Yr 1-4 (restatement from pg 1)	BYU Subaward Yr 5			
a. Personnel	$ 51,000.00	$ 9,000.00	$	$	$ 60,000.00
b. Fringe Benefits	5,189.00	173.00			5,362.00
c. Travel	0.00	0.00			
d. Equipment	0.00	0.00			
e. Supplies	850.00	0.00			850.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	17,500.00	0.00			17,500.00
i. Total Direct Charges (sum of 6a-6h)	74,539.00	9,173.00			$ 83,712.00
j. Indirect Charges	28,721.00	4,587.00			$ 33,308.00
k. TOTALS (sum of 6i and 6j)	$ 103,260.00	$ 13,760.00	$	$	$ 117,020.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

Standard Form 424A (Rev. 7- 97)
Prescribed by OMB (Circular A -102) Page 1A

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) NCSU Subaward Yr 1	(2) NCSU Subaward Yr 2	(3) NCSU Subaward Yr 3	(4) NCSU Subaward Yr 4	(5)
a. Personnel	$ 8,340.00	$ 0.00	$ 0.00	$ 0.00	$ 8,340.00
b. Fringe Benefits	1,184.00	0.00	0.00	0.00	1,184.00
c. Travel	707.00	0.00	0.00	0.00	707.00
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	0.00	0.00	0.00	0.00	
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	0.00	0.00	0.00	0.00	
i. Total Direct Charges (sum of 6a-6h)	10,231.00	0.00	0.00	0.00	$ 10,231.00
j. Indirect Charges	5,269.00	0.00	0.00	0.00	$ 5,269.00
k. TOTALS (sum of 6i and 6j)	$ 15,500.00	$ 0.00	$ 0.00	$ 0.00	$ 15,500.00
7. Program Income	$ 0.00	$ 0.00	$ 0.00	$ 0.00	$

Authorized for Local Reproduction

Standard Form 424A (Rev. 7- 97)
Prescribed by OMB (Circular A -102) Page 1A

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) NCSU Subaward Yr 1-4 (restatement from pg 1)	(2) NCSU Subaward Yr 5	(3)	(4)	(5)
a. Personnel	$ 8,340.00	$ 0.00	$	$	$ 8,340.00
b. Fringe Benefits	1,184.00	0.00			1,184.00
c. Travel	707.00	0.00			707.00
d. Equipment	0.00	0.00			
e. Supplies	0.00	0.00			
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	0.00	0.00			
i. Total Direct Charges (sum of 6a-6h)	10,231.00	0.00			$ 10,231.00
j. Indirect Charges	5,269.00	0.00			$ 5,269.00
k. TOTALS (sum of 6i and 6j)	$ 15,500.00	$ 0.00	$	$	$ 15,500.00
7. Program Income	$ 0.00	$ 0.00	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) TTU Subaward Yr 1	(2) TTU Subaward Yr 2	(3) TTU Subaward Yr 3	(4) TTU Subaward Yr 4	(5)
a. Personnel	$ 24,750.00	$ 33,990.00	$ 26,257.00	$ 0.00	$ 84,997.00
b. Fringe Benefits	6,188.00	8,498.00	6,564.00	0.00	21,250.00
c. Travel	0.00	0.00	0.00	0.00	
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	4,325.00	0.00	1,500.00	0.00	5,825.00
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	10,045.00	10,443.00	10,857.00	100.00	31,445.00
i. Total Direct Charges (sum of 6a-6h)	45,308.00	52,931.00	45,178.00	100.00	$ 143,517.00
j. Indirect Charges	17,328.00	20,868.00	16,866.00	49.00	$ 55,111.00
k. TOTALS (sum of 6i and 6j)	$ 62,636.00	$ 73,799.00	$ 62,044.00	$ 149.00	$ 198,628.00
7. Program Income	$ 0.00	$ 0.00	$ 0.00	$ 0.00	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) TTU Subaward Yr 1-4 (restatement from pg 1)	(2) TTU Subaward Yr 5	(3)	(4)	(5)
a. Personnel	$ 84,997.00	$ 0.00	$	$	$ 84,997.00
b. Fringe Benefits	21,250.00	0.00			21,250.00
c. Travel	0.00	0.00			
d. Equipment	0.00	0.00			
e. Supplies	5,825.00	0.00			5,825.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	31,445.00	100.00			31,545.00
i. Total Direct Charges (sum of 6a-6h)	143,517.00	100.00			$ 143,617.00
j. Indirect Charges	55,111.00	49.00			$ 55,160.00
k. TOTALS (sum of 6i and 6j)	$ 198,628.00	$ 149.00	$	$	$ 198,777.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) UWRI Subaward Yr 1	(2) UWRI Subaward Yr 2	(3) UWRI Subaward Yr 3	(4) UWRI Subaward Yr 4	(5)
a. Personnel	$ 103,588.00	$ 106,694.00	$ 105,597.00	$ 108,765.00	$ 424,644.00
b. Fringe Benefits	0.00	0.00	0.00	0.00	
c. Travel	29,400.00	16,800.00	17,600.00	16,800.00	80,600.00
d. Equipment	0.00	0.00	0.00	0.00	
e. Supplies	6,400.00	3,160.00	3,160.00	3,160.00	15,880.00
f. Contractual	0.00	0.00	0.00	0.00	
g. Construction	0.00	0.00	0.00	0.00	
h. Other	0.00	0.00	0.00	0.00	
i. Total Direct Charges (sum of 6a-6h)	139,388.00	126,654.00	126,357.00	128,725.00	$ 521,124.00
j. Indirect Charges	26,598.00	24,699.00	24,639.00	25,113.00	$ 101,049.00
k. TOTALS (sum of 6i and 6j)	$ 165,986.00	$ 151,353.00	$ 150,996.00	$ 153,838.00	$ 622,173.00
7. Program Income	$ 53,300.00	$ 68,300.00	$ 94,650.00	$ 99,650.00	$ 315,900.00

Authorized for Local Reproduction

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				Total
	(1) UWRI Subaward Yr 1-4 (restatement from pg 1)	(2) UWRI Subward Yr 5	(3)	(4)	(5)
a. Personnel	$ 424,644.00	$ 112,028.00	$	$	$ 536,672.00
b. Fringe Benefits	0.00				
c. Travel	80,600.00	16,800.00			97,400.00
d. Equipment	0.00	0.00			
e. Supplies	15,880.00	3,160.00			19,040.00
f. Contractual	0.00	0.00			
g. Construction	0.00	0.00			
h. Other	0.00	0.00			
i. Total Direct Charges (sum of 6a-6h)	521,124.00	131,988.00			$ 653,112.00
j. Indirect Charges	101,049.00	25,766.00			$ 126,815.00
k. TOTALS (sum of 6i and 6j)	$ 622,173.00	$ 157,754.00	$	$	$ 779,927.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

Budget Justification for SF424A line items

OVERALL PROJECT BUDGET TO UNIV. OF TEXAS

Center Costs supported by Federal cooperative agreement	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	$183,589	$249,506	$256,991	$263,225	$227,299	**$1,180,610**
b. Fringe Benefits	$55,076	$74,851	$77,098	$78,968	$68,190	**$354,183**
c. Travel	0	0	0	0	0	**0**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	$15,200	$9,100	$4,400	$4,400	$4,400	**$37,500**
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	$336,487	$330,166	$319,677	$248,179	$221,263	**$1,455,772**
i. Total Direct Costs	$590,353	$663,624	$658,165	$594,772	$521,152	**$3,028,065**
j. Indirect Costs	$198,773	$196,911	$197,608	$202,067	$176,379	**$971,738**
Total	**$789,125**	**$860,535**	**$855,774**	**$796,839**	**$697,531**	**$3,999,803**

Center Income (expenses) for non-federal income	Year 1	Year 2	Year 3	Year 4	Year 5	Total
7. Program Income	$53,300	$68,300	$94,650	$99,650	$133,650	**$449,550**
R&D management expenses	($8,883)	($11,383)	($15,775)	($16,608)	($22,275)	**($74,924)**
Income-dependent R&D expenses	($44,417)	($56,971)	($78,875)	($83,042)	($111,375)	**($374,626)**
Net to Center	**0**	**0**	**0**	**0**	**0**	**0**

Justifications for individual line items are broken down by subproject (ADMIN, OUTREACH, CODE, RESEARCH) in following pages. The "Other" category of the UT budget includes subawards (BYU, UWRI, TTU, NCSU), which are provided separate justifications after the UT pages. A separate justification is also provided for non-Federal program income and expenses.

Budget Justification for SF424A line items
Outreach subproject

Costs supported by Federal cooperative agreement	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	35,174	$36,230	$37,316	$36,960	$38,069	**$183,749**
b. Fringe Benefits	$10,552	$10,870	$11,195	$11,088	$11,421	**$55,126**
c. Travel	0	0	0	0	0	**0**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	$6,400	$1,300	$1,300	$1,300	$1,300	**$11,600**
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	$225,788	$223,317	$223,983	$213,930	$186,314	**$1,073,332**
i. Total Direct Costs	$277,914	$271,717	$273,794	$263,278	$237,104	**$1,323,807**
j. Indirect Costs	$54,321	$28,909	$27,616	$27,361	$28,155	**$166,362**
Total	**$323,235**	**$300,626**	**$301,410**	**$290,639**	**$265,259**	**$1,490,169**

Center Income (expenses) for non-federal income	Year 1	Year 2	Year 3	Year 4	Year 5	Total
7. Program Income	$53,300	$68,300	$94,650	$99,650	$133,650	**$449,550**
R&D management expenses	($8,883)	($11,383)	($15,775)	($16,608)	($22,275)	**($74,924)**
Income-dependent R&D expenses	($44,417)	($56,971)	($78,875)	($83,042)	($111,375)	**($374,626)**
Net to Center	**0**	**0**	**0**	**0**	**0**	**0**

Line item breakdown and justifications of Federal costs are provided below. Program Income and expenses are provided separate justification pages.

a. Personnel: Salaried positions for subproject work includes annual merit/cost of living increase over starting monthly base rate of 3%. Person months worked per year and salary costs shown in table below.

PERSONNEL Position	Monthly Base Salary	Year 1 months / cost	Year 2 months / cost	Year 3 months / cost	Year 4 months / cost	Year 5 months / cost	Total months / cost
PI, B. Hodges	$10,646	0.15 / $1,597	0.15 / $1,645	0.15 / $1,694	0.15 / $1,745	0.15 / $1,797	0.75 / $8,478
co-PI, F. Leite	$10,000	0.5 / $5,000	0.5 / $5,150	0.5 / $5,305	0.5 / $5,464	0.5 / $5,628	2.5 / $26,547
co-PI, C. Rowney	$13,505	0.35 / $4,727	0.35 / $4,869	0.35 / $5,015	0.35 / $5,165	0.35 / $5,320	1.75 / $25,096
Research Scientist	$9,000	0.15 / $1,350	0.15 / $1,391	0.15 / $1,432	0	0	0.45 / $4,173
Grad. Research Assistant	12 / $1,875	12 / $22,500	12 / $23,175	12 / $23,870	12 / $24,586	12 / $25,324	60 / $119,455
Total Personnel		**13.15 / $35,174**	**13.15 / $36,230**	**13.15 / $37,316**	**13 / $36,960**	**13 / $38,069**	**65.45 / $183,749**

b. Fringe Benefits: applied at standard rates, which are estimated at 30% of personnel salaries.

FRINGE BENEFITS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Total on all salaries	$10,552	$10,870	$11,195	$11,088	$11,421	**$55,126**

c. Travel: All travel will on this subproject will be coordinated through the UWRI subaward.

d. Equipment: No special equipment will be purchased for use in this research subproject

e. Supplies: Funds requested for computer hardware (non-capitalized), computer supplies and software.

SUPPLIES	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Laptop computer	$1,600	0	0	0	0	**$1,600**
Desktop computer	$3,500	0	0	0	0	**$3,500**
Computer supplies and software	$1,300	$1,300	$1,300	$1,300	$1,300	**$6,500**
Total	**$6,400**	**$1,300**	**$1,300**	**$1,300**	**$1,300**	**$11,600**

f. Contractual: No contractual costs are anticipated on this subproject.

g. Construction: No construction costs are anticipated on this subproject.

h. Other:

OTHER	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Publication costs	$400	$400	$400	$400	$400	**$2,000**
Tuition	$12,163	$12,650	$13,250	$13,700	$14,400	**$66,163**
Subaward BYU	$21,239	$32,224	$31,937	$17,860	$13,760	**$117,020**
Subaward UWRI	$165,986	$151,353	$150,996	$153,838	$157,754	**$779,927**
Workshops (see details in table below)	$26,000	$26,690	$27,400	$28,132	0	**$108,222**
Total	**$225,788**	**$223,317**	**$223,983**	**$213,930**	**$186,314**	**$1,073,332**

Publication costs: Fees for open-source publishing of journal articles.

Tuition: The University of Texas at Austin requires payment for tuition and fees from research projects as a portion of compensation for graduate research assistants. Estimated graduate student tuition increase of 4% per year is applied.

Subawards: (see separate institution budget justification sheets for line-item breakdown)

Workshops: One workshop per year to develop user and model developer community in years 1-4. Ten individuals (outside of this cooperative agreement's participants) will be supported with attendance stipends, travel, and lodging/subsistence. Inflation rate of 3% per year is applied to all estimated costs except the participant stipends. Travel costs averaging $1250 per traveler were estimated by including airfare, rental car, and/or taxi. These average costs are based on a portion of the attendees being international travelers (e.g. 4 x $2225 per ticket), while the remainder of the attendees arrive on domestic flights (airfares e.g. 6 x $600 per ticket). The proportion of international and domestic attendees will be determined each year depending on available airfares, potential attendees' home locations, collaborator interests, and ensuring we stay within planned budget. Lodging and subsistence per traveler is estimated using 2 nights lodging at $100 per night and 3 days subsistence at $50 per day.

WORKSHOPS	**# of supported participants**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total Cost**
Participant stipends	10	$3,000	$3,000	$3,000	$3,000	0	**$12,000**
Travel	10	$12,500	$12,875	$13,261	$13,659	0	**$52,295**
Lodging/subsistence	10	$3,500	$3,605	$3,713	$3,824	0	**$14,642**
Meeting space		$7,000	$7,210	$7,426	$7,649	0	**$29,285**
Total		**$26,000**	**$26,690**	**$27,400**	**$28,132**	**0**	**$108,222**

i. Total direct costs: Includes all of a-h above.

j. Indirect Costs: Indirect costs (see table below) are calculated at the federally approved rate of 55% of the Modified Total Direct Costs (MTDC). Equipment (of which there is none), Tuition, and Workshop costs are excluded from MTDC. Subawards are charged the indirect rate only on the first $25,000 to each subcontractor.

INDIRECT COSTS	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total Cost**
i. Total Direct Costs	$277,914	$271,717	$273,794	$263,278	$237,104	**$1,323,807**
ii. (Tuition)	($12,163)	($12,650)	($13,250)	($13,700)	($14,400)	**($66,163)**
iii. (Workshop)	($26,000)	($26,690)	($27,400)	($28,132)	0	**($108,222)**
iv. (Subaward BYU over $25,000 cumulative)	(0)	($28,463)	($31,937)	($17,860)	($13,760)	**($92,020)**
v. (Subaward UWRI over $25,000)	($140,986)	($151,353)	($150,996)	($153,838)	($157,754)	**($754,927)**
Modified Total Direct Costs (MTDC) i minus ii through iv above.	**$98,765**	**$52,561**	**$50,211**	**$49,748**	**$51,190**	**$302,475**
Indirect (55% of MTDC)	**$54,321**	**$28,909**	**$27,616**	**$27,361**	**$28,155**	**$166,362**

7. Program Income: See separate justification sheet for Program Income and Expenses.

Budget Justification for SF424A line items

Research Subproject

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	$94,017	$96,837	$99,743	$102,734	$85,630	**$478,961**
b. Fringe Benefits	$28,205	$29,052	$29,923	$30,820	$25,689	**$143,689**
c. Travel	0	0	0	0	0	**0**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	$1,600	$1,600	$1,600	$1,600	$1,600	**$8,000**
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	$48,063	$33,050	$33,650	$34,100	$34,800	**$183,663**
i. Total Direct Costs	$171,885	$160,539	$164,916	$169,254	$147,719	**$814,313**
j. Indirect Costs	$87,847	$81,339	$83,416	$85,555	$73,325	**$411,482**
Total	**$259,732**	**$241,878**	**$248,332**	**$254,809**	**$221,044**	**$1,225,795**

a. Personnel: Salaried positions for subproject work includes annual merit/cost of living increase over starting monthly base rate of 3%. Person months worked per year and salary costs shown in table below.

PERSONNEL Position	Monthly Base Salary	Year 1 months / cost	Year 2 months / cost	Year 3 months / cost	Year 4 months / cost	Year 5 months / cost	Total months / cost
PI, B. Hodges	$10,646	0.60 / $6,388	0.60 / $6,579	0.60 / $6,777	0.60 / $6,980	0.60 / $7,189	**3.0 / $33,913**
co-PI M. Barrett	$13,505	0.75 / $10,129	0.75 / $10,433	0.75/ $10,746	0.75 / $11,068	0.75 / 11,400	**3.75 / $53,776**
Post-doctoral Associate	$5,000	11 / $55,000	11 / $56,650	11 / $58,350	11 / $60,100	7.5/ $41,717	**51.5/ $272,847**
Grad. Research Assistant	12 / $1,875	12 / $22,500	12 / $23,175	12 / $23,870	12 / $24,586	12 / $25,324	**60 / $119,455**
Total Personnel		**24.35 / $94,017**	**24.35 / $96,837**	**24.35 / $99,743**	**24.35 / $102,734**	**20.85 / $85,630**	**118.25 / $478,961**

b. Fringe Benefits: applied at standard rates, which are estimated at 30% of personnel salaries.

FRINGE BENEFITS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Total on all salaries	$28,205	$29,052	$29,923	$30,820	$25,689	**$143,689**

c. Travel: All travel will be coordinated through the UWRI subaward in Outreach Subproject.

d. Equipment: No special equipment will be purchased for use in this research subproject

e. Supplies: Funds requested for computer supplies and software.

SUPPLIES	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Computer supplies and software	$1,600	$1,600	$1,600	$1,600	$1,600	**$8,000**

f. Contractual: No contractual costs are anticipated on this subproject.

g. Construction: No construction costs are anticipated on this subproject.

h. Other:
Publication costs: Fees for open-source publishing of journal articles.
Tuition: The University of Texas at Austin requires payment for tuition and fees from research projects as a portion of compensation for graduate research assistants. Estimated graduate student tuition increase of 4% per year is applied.

Subawards: Unassigned awards are to be used in developing the research community for new features in the models. See separate institution budget justification sheet for line-item breakdown of NCSU.

OTHER	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Publication costs	$400	$400	$400	$400	$400	**$2,000**
Tuition	$12,163	$12,650	$13,250	$13,700	$14,400	**$66,163**
Subaward NCSU	$15,500	0	0	0	0	**$15,500**
Subaward (unassigned)	$20,000	$20,000	$20,000	$20,000	$20,000	**$100,000**
Total	**$48,063**	**$33,050**	**$33,650**	**$34,100**	**$34,800**	**$183,663**

i. Total direct costs: Includes all of a-h above.

j. Indirect Costs: Indirect costs (see table below) are calculated at the federally approved rate of 55% of the Modified Total Direct Costs (MTDC. Equipment (of which there is none), Tuition, and Workshop costs are excluded from MTDC. Subawards are charged the indirect rate only on the first $25,000 to each subcontractor.

INDIRECT COSTS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
i. Total Direct Costs	$171,885	$160,539	$164,916	$169,254	$147,719	**$814,313**
ii. (Tuition)	($12,163)	($12,650)	($13,250)	($13,700)	($14,400)	**($66,163)**
iiii. (Subaward NCSU over $25,000 cumulative)	0	0	0	0)	0	**0**
Modified Total Direct Costs (MTDC) i minus ii through iii above.	**$159,722**	**$147,889**	**$151,666**	**$155,554**	**$133,319**	**$748,150**
Indirect (55% of MTDC)	**$87,847**	**$81,339**	**$83,416**	**$85,555**	**$73,325**	**$411,482**

Budget Justification for SF424A line items

Code Subproject

BUDGET	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	$24,673	$87,212	$89,829	$92,524	$72,789	**$367,027**
b. Fringe Benefits	$7,402	$26,163	$26,948	$27,758	$21,837	**$110,108**
c. Travel	0	0	0	0	0	**0**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	$5,200	$5,200	$500	$500	$500	**$11,900**
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	$62,636	$73,799	$62,044	$149	$149	**$198,777**
i. Total Direct Costs	$99,911	$192,374	$179,321	$120,931	$95,275	**$687,812**
j. Indirect Costs	$34,251	$65,216	$64,502	$66,430	$52,319	**$282,718**
Total	**$134,162**	**$257,590**	**$243,823**	**$187,361**	**$147,594**	**$970,530**

a. Personnel: Salaried positions for subproject work includes annual merit/cost of living increase over starting monthly base rate of 3%. Person months worked per year and salary costs shown in table below.

PERSONNEL Position	Monthly Base Salary	Year 1 months / cost	Year 2 months / cost	Year 3 months / cost	Year 4 months / cost	Year 5 months / cost	Total months / cost
PI, B. Hodges	$10,646	0.75 / $7,985	0.75 / $8,224	0.75 / $8,471	0.75 / $8,725	0.75 / $8,987	**3.75 / $42,392**
Research Fellow	$11,125	1.5 / $16,688	1.5 / $17,188	1.5 / $17,704	1.5 / $18,235	1.5 / 18,782	**7.5 / $88,597**
Post-doctoral Associate	$5,000	0 / $0	12 / $61,800	12 / $63,654	12 / $65,564	8 / $45,020	**44/ $236,038**
Total Personnel		**2.25 / $24,672**	**14.25 / $87,212**	**14.25 / $89,829**	**14.25 / $92,523**	**14.25 / $72,789**	**55.25 / $367,027**

b. Fringe Benefits: applied at standard rates, which are estimated at 30% of personnel salaries.

FRINGE BENEFITS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Total on all salaries	$7,402	$26,163	$26,948	$27,758	$21,837	**$110,108**

c. Travel: All travel will be coordinated through the UWRI subaward in Outreach Subproject.

d. Equipment: No special equipment will be purchased for use in this research subproject

e. Supplies: Funds requested for computer hardware (non-capitalized), computer supplies and software.

SUPPLIES	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Computer Workstation	$4,700	$4,700	0	0	0	**$9,400**
Computer supplies and software	$500	$500	$500	$500	$500	**$2,500**
Total	**$5,200**	**$5,200**	**$500**	**$500**	**$500**	**$11,900**

f. Contractual: No contractual costs are anticipated on this subproject.

g. Construction: No construction costs are anticipated on this subproject.

h. Other:

Subaward: (see separate institution budget justification sheets for line-item breakdown)

OTHER	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Subaward TTU	$62,636	$73,799	$62,044	$149	$149	**$198,777**

i. Total direct costs: Includes all of a-h above.

j. Indirect Costs: Indirect costs (see table below) are calculated at the federally approved rate of 55% of the Modified Total Direct Costs (MTDC. Equipment (of which there is none), Tuition, and Workshop costs are excluded from MTDC. Subawards are charged the indirect rate only on the first $25,000 to each subcontractor.

INDIRECT COSTS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Total Direct Costs	$99,911	$192,374	$179,321	$120,931	$95,275	**$687,812**
(Subaward TTU over $25,000)	($37,636)	($73,799)	($62,044)	($149)	($149)	**($173,777)**
Modified Total Direct Costs (MTDC)	**$62,275**	**$118,575**	**$117,277**	**$120,782**	**$95,126**	**$514,035**
Indirect (55% of MTDC)	**$34,251**	**$65,216**	**$64,502**	**$66,430**	**$52,319**	**$282,718**

Budget Justification for SF424A line items

Administrative Subproject

BUDGET	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	$29,725	$29,227	$30,103	$31,007	$30,811	**$150,873**
b. Fringe Benefits	$8,918	$8,768	$9,031	$9,303	$9,243	**$45,263**
c. Travel	0	0	0	0	0	**0**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	$2,000	$1,000	$1,000	$1,000	$1,000	**$6,000**
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	0	0	0	0	0	**0**
i. Total Direct Costs	$40,643	$38,995	$40,134	$41,310	$41,054	**$202,136**
j. Indirect Costs	$22,354	$21,447	$22,074	$22,721	$22,580	**$111,176**
Total	**$62,997**	**$60,442**	**$62,208**	**$64,031**	**$63,634**	**$313,312**

a. Personnel: Salaried positions for subproject work includes annual merit/cost of living increase over starting monthly base rate of 3%. Person months worked per year and salary costs shown in table below.

PERSONNEL Position	Monthly Base Salary	Year 1 months / cost	Year 2 months / cost	Year 3 months / cost	Year 4 months / cost	Year 5 months / cost	Total months / cost
PI, B. Hodges	$10,646	0.50 / $5,323	0.50 / $5,483	0.50 / $5,647	0.50 / $5,817	0.50 / $5,991	2.5 / $28,261
co-PI M. Barrett	$13,505	0.25 / $3,376	0.15 / $2,087	0.15/ $2,149	0.15 / $2,214	0.15 / $2,280	0.85 / $12,106
co-PI C. Rowney	$13,505	0.15 / $2,026	0.15 / $2,087	0.15/ $2,149	0.15 / $2,214	0.15 / $2,280	0.75 / $10,756
Post-doctoral Associate	$5,000	1 / $5,000	1 / $5,150	1 / $5,305	1 / $5,464	1 / $5,628	5 / $26,547
Clerical	$5,000	2.2 / $11,000	2.2 / $11,330	2.2 / $11,670	2.2 / $12,020	2.0 / $11,255	10.8 / $57,275
Computer Technician	$5,000	0.6 / $3,000	0.6 / $3,090	0.6 / $3,183	0.6 / $3,278	0.6 / $3,377	3.0 / $15,928
Total Personnel		**4.7 / $29,725**	**4.6 / $29,227**	**4.6 / $30,103**	**4.6 / $31,007**	**4.4 / $30,811**	**58.75 / $150,873**

b. Fringe Benefits: applied at UT standard rates, which are 30% of personnel salaries.

FRINGE BENEFITS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Total on all salaries	$8,918	$8,768	$9,031	$9,303	$9,243	$45,263

c. Travel: All travel will be coordinated through the UWRI subcontract in Outreach Subproject.

d. Equipment: No special equipment will be purchased for use in this subproject

e. Supplies: Funds requested for computer supplies and software.

SUPPLIES	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Computer supplies and software	$2,000	$1,000	$1,000	$1,000	$1,000	$6,000

f. Contractual: No contractual costs are anticipated on this subproject.

g. Construction: No construction costs are anticipated on this subproject.

h. Other: There are no other costs on this subproject.

i. Total direct costs: Includes all of a-h above.

j. Indirect Costs: Indirect costs (see table below) are calculated at the federally approved rate of 55% of the Modified Total Direct Costs (MTDC. Equipment (of which there is none), Tuition, and Workshop costs are excluded from MTDC. Subawards are charged the indirect rate only on the first $25,000 to each subcontractor.

INDIRECT COSTS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
i. Total Direct Costs	$40,643	$38,995	$40,134	$41,310	$41,054	$202,136
ii. (Tuition)	0	0	0	0)	0	0
iiii. (Subaward over $25,000 cumulative)	0	0	0	0)	0	0
Modified Total Direct Costs (MTDC) i minus ii through iii above.	**$40,643**	**$38,995**	**$40,134**	**$41,310**	**$41,054**	**$202,136**
Indirect (55% of MTDC)	**$22,354**	**$21,447**	**$22,074**	**$22,721**	**$22,580**	**$111,176**

Budget Justification for SF424A line items

PROGRAM INCOME

The Program Income in the center is developed from three sources: teaching courses, support subscriptions from users, and partner contributions from industry. Expenses for running the courses offset the gross income. The Program Income will be used fund further research and development of the models. Managing this additional research will require some administrative expenses, that will also be covered by the Program Income. We plan the net budget of the Center is zero for each year.

COURSE INCOME	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Number of courses	2	2	4	4	4	**16**
Number of locations	4	4	4	4	6	**22**
Students per location per course	10	10	10	10	10	**n/a**
Total number of students	80	80	160	160	240	**720**
Course Fees per student	$1000	$1000	$1000	$1000	$1000	**n/a**
Course income	**$80,000**	**$80,000**	**$160,000**	**$160,000**	**$240,000**	**$720,000**

COURSE EXPENSES	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Administrative costs	$9,600	$9,600	$19,200	$19,200	$19,200	**$76,800**
Accounting costs	$3000	$3000	$3750	$3750	$3750	**$17,250**
Speaker fees ($4500 per course taught)	$36,000	$36,000	$72,000	$72,000	$108,000	**$324,000**
Travel (transport)	$3,700	$3,700	$7,400	$7,400	$12,200	**$34,400**
Travel (lodging and meals)	$2,400	$2,400	$4,800	$4,800	$8,000	**$22,400**
Handout reproduction and media	$1,600	$1,600	$3,200	$3,200	$4,800	**$14,400**
LED projector	$400	$400			$400	**$1,200**
Course expenses	**$23,300**	**$23,300**	**$49,650**	**$49,650**	**$83,650**	**$229,550**

OTHER INCOME	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Support Subscriptions	0	$5,000	$5,000	$10,000	$10,000	**$30,000**
Partner Contributions	$30,000	$40,000	$40,000	$40,000	$40,000	**$190,000**
Other Income	**$30,000**	**$45,000**	**$45,000**	**$50,000**	**$50,000**	**$229,550**

NET INCOME	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Course Income (from above)	$80,000	$80,000	$160,000	$160,000	$240,000	**$720,000**
Course expenses (from above)	$23,300	$23,300	$49,650	$49,650	$83,650	**$229,550**
Other income (from above)	$30,000	$45,000	$45,000	$50,000	$50,000	**$229,550**
PROGRAM INCOME (net income available for research)	**$53,300**	**$68,300**	**$94,650**	**$99,650**	**$133,650**	**$449,550**

RESEARCH AND DEVELOPMENT FUNDED BY INCOME	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Income-dependent R&D funded (external or internal)	$44,417	$56,971	$78,875	$83,042	$111,375	**$374,626**
R&D management expenses	$8,883	$11,383	$15,775	$16,608	$22,275	**$74,924**
Sum of R&D funding and expenses	**$53,300**	**$68,300**	**$94,650**	**$$99,650**	**$133,650**	**$449,550**
NET TO CENTER (Program Income minus R&D funding and expenses)	**0**	**0**	**0**	**0**	**0**	**0**

Budget Justification for SF424A line items

BYU Subaward

Subaward budget to BYU by SF424A categories:

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	$12,000	$15,000	$15,000	$9,000	$9,000	**$60,000**
b. Fringe Benefits	$1,634	$1,691	$1,691	$173	$173	**$5,362**
c. Travel	0	0	0	0	0	**0**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	$525	$325	0	0	0	**$850**
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	0	$6,700	$6,900	$3,900	0	**$17,500**
i. Total Direct Costs	$14,159	$23,716	$23,591	$13,073	$9,173	**$83,712**
j. Indirect Costs	$7,080	$8,508	$8,346	$4,787	$4,587	**$33,308**
Total	**$21,239**	**$32,224**	**$31,937**	**$17,860**	**$13,760**	**117,020**

Line-item breakdown of subaward:

a. Personnel: Person months worked per year and salary costs shown in table below.

PERSONNEL Position	Monthly Base Salary	Year 1 months / cost	Year 2 months / cost	Year 3 months / cost	Year 4 months / cost	Year 5 months / cost	Total months / cost
Co-PI D. Ames	$12,000	0.50 / $6,000	0.50 / $6,000	0.50 / $6,000	0 / $0	0 / $0	**1,5 / $18,000**
Grad. Research Assistant	$1,000	0 / $0	9 / $9,000	9 / $9,000	4.5 / $4,500	0 / $0	**22.5 / $22,500**
Undergraduate Research Assistant	$1,000	6 / $6,000	0 / $0	0/ $0	4.5 / $4,500	9 / $9,000	**19,5 / $19,500**
Total Personnel		**6.5 / $12,000**	**9,5 / $15,000**	**9,5 / $15,000**	**9 / $9,000**	**9 / $9,000**	**43.5 / $60,000**

b. Fringe Benefits: applied at 25% for co-PI and 2% for students.

FRINGE BENEFITS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Co-PI	$1,518	$1,518	$1,518	0	0	**$4,554**
Students	$116	$173	$173	$173	$173	**$808**
Total on all salaries	**$1,634**	**$1,691**	**$1,691**	**$173**	**$173**	**$5,362**

c. Travel: All travel on this subaward will be coordinated through the UWRI subaward in Outreach Subproject.

d. Equipment: No special equipment will be purchased for use in this research subaward

e. Supplies: Funds requested for computer supplies and software.

SUPPLIES	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Computer supplies and software	$525	$325	0	0	0	$850

f. Contractual: No contractual costs are anticipated on this subaward.

g. Construction: No construction costs are anticipated on this subaward.

h. Other:

Publication costs: Fees for open-source publishing of journal articles.

Tuition: Tuition and fees are provided for graduate student research assistants.

OTHER	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Publication costs	0	0	0	$400	0	$400
Tuition	0	$6,700	$6,900	$3,500	0	$17,100
Total	**0**	**$6,700**	**$6,900**	**$3,900**	**$0**	**$17,500**

i. Total direct costs: Includes all of a-h above.

j. Indirect Costs: Indirect costs (see table below) are calculated at the federally approved rate of 50% of the Modified Total Direct Costs (MTDC. Equipment (of which there is none) and Tuition are excluded from MTDC.

INDIRECT COSTS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
i. Total Direct Costs	$14,159	$23,716	$23,591	$19,073	$9,173	$83,712
ii. (Tuition)	0	($6,700)	($6,900)	($3,500)	0	($17,100)
Modified Total Direct Costs (MTDC) i minus ii above.	**$14,159**	**$17,016**	**$16,691**	**$9,573**	**$9,173**	**$66,612**
Indirect (50% of MTDC)	**$7,080**	**$8,508**	**$8,346**	**$4,787**	**$4,587**	**$33,308**

Budget Justification for SF424A line items

NCSU Subaward

Subaward budget to NCSU by SF424A categories:

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	$8,340	0	0	0	0	**$8,340**
b. Fringe Benefits	$1,184	0	0	0	0	**$1,184**
c. Travel	$707	0	0	0	0	**$707**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	0	0	0	0	0	**0**
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	0	0	0	0	0	**0**
i. Total Direct Costs	$10,231	0	0	0	0	**$10,321**
j. Indirect Costs	$5,269	0	0	0	0	**$5,269**
Total	**15,500**	**0**	**0**	**0**	**0**	**$15,500**

Line-item breakdown of subaward:

a. Personnel: Person-months worked per year and salary costs shown in table below. Graduate research assistant employed for 3 months during summer and undergraduate research assistant at a rate of $12/hr for 170 hours.

PERSONNEL Position	Monthly Base Salary	Year 1 months / cost	Year 2 months / cost	Year 3 months / cost	Year 4 months / cost	Year 5 months / cost	Total months / cost
Grad. Research Assistant	$2,100	3 / $6,300	0	0	0	0	**3 / $6,300**
Undergrad Research Assistant	$2,040	1 / $2,040	0	0	0	0	**1 / $2,040**
Total		**4 / $8,340**	**0**	**0**	**0**	**0**	**4 / $8,340**

b. Fringe Benefits: applied at 16% for graduate students and 8.65% for undergraduate students.

FRINGE BENEFITS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Grad. Research Assistant	$1,008	0	0	0	0	**$1,008**
Undergrad Research Assistant	$176	0	0	0	0	**$176**
Total	$1,184	0	0	0	0	**$1,184**

c. Travel:

Travel Overview

TRAVEL	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Austin for technical meeting	$707	0	0	0	0	**$707**

Trip Breakdown

TRAVEL Year 1 Location and purpose	# trips	# people per trip	# nights per trip	# ground transport days per person per trip	air fare per person per trip	car, taxi, ground trans. per person per ground days	meals and lodging per person per night per trip	total cost
Austin for technical meeting	1	1	2	2	$367	$50	$120	**$707**

d. Equipment: No special equipment will be purchased for use in this research subaward

e. Supplies: No supplies are requested for this subaward

f. Contractual: No contractual costs are anticipated on this subaward

g. Construction: No construction costs are anticipated on this subaward

h. Other: No other costs are anticipated on this subaward

i. Total direct costs: Includes all of a-h above.

j. Indirect Costs: Indirect costs (see table below) are calculated at the federally approved rate of 51.5% of Total Direct Costs (MTDC). Equipment (of which there is none) and Tuition (of which there is none) are excluded from MTDC.

INDIRECT COSTS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Total Direct Costs	$10,231	0	0	0	0	$10,321
Indirect (51.5% of MTDC)	**$5,269**	**0**	**0**	**0**	**0**	**$5,269**

Budget Justification for SF424A line items

TTU Subaward

Subaward budget to TTU by SF424A categories:

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	$24,750	$33,990	$26,257	0	0	**$84,997**
b. Fringe Benefits	$6,188	$8,498	$6,564	$0	$0	**$21,250**
c. Travel	0	0	0	0	0	**0**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	$4,325	0	$1,500	0	0	**$5,825**
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	$10,045	$10,443	$10,857	$100	$100	**$31,545**
i. Total Direct Costs	$45,308	$52,931	$45,178	$100	$100	**$83,712**
j. Indirect Costs	$17,328	$20,868	$16,866	$49	$49	**$55,160**
Total	**$62,636**	**$73,799**	**$62,044**	**$149**	**$149**	**$198,777**

Line-item breakdown of subaward:

a. Personnel: Person months worked per year and salary costs shown in table below. Estimated salaries are inflated by 3% per year for cost of living. Note that co-PI Cleveland has salary as a Research Fellow at UT under the Code Subproject, and so does not have any salary directly in this subaward.

PERSONNEL Position	Monthly Base Salary	Year 1 months / cost	Year 2 months / cost	Year 3 months / cost	Year 4 months / cost	Year 5 months / cost	Total months / cost
Grad. Research Assistant	$2,750	9 / $24,750	12 / $33,990	9 / $26,257	0 / $0	0 / $0	**30 / $84,997**

b. Fringe Benefits: applied at 25% for students.

FRINGE BENEFITS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Students	$6,188	$8,498	$6,564	$0	$0	**$21,250**

c. Travel: All travel will be coordinated through the UWRI subcontract in Outreach Subproject.

d. Equipment: No special equipment will be purchased for use in this research subaward.

e. Supplies: Funds requested for computer supplies and software including Embarcadero Delphi-10 software development application in year 1 and upgrade in year 3.

SUPPLIES	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Computer supplies and software	$4,325	0	$1,500	0	0	$5,825

f. Contractual: No contractual costs are anticipated on this subaward.

g. Construction: No construction costs are anticipated on this subaward.

h. Other:

Publication costs: Fees for open-source publishing of journal articles.

Tuition: Tuition and fees are provided for graduate student research assistants.

OTHER	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Publication costs	$100	$100	$100	$100	$100	$500
Tuition	$9,945	$10,343	$10,757	0	0	$31,045
Total	**$10,045**	**$10,443**	**$10,857**	**$100**	**$100**	**$31,545**

i. Total direct costs: Includes all of a-h above.

j. Indirect Costs: Indirect costs (see table below) are calculated at the federally approved rate of 49% of the Modified Total Direct Costs (MTDC). Equipment (of which there is none) and Tuition are excluded from MTDC.

INDIRECT COSTS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
i. Total Direct Costs	$45,308	$52,931	$45,178	$100	$100	$83,712
ii. (Tuition)	($9,945)	($10,343)	($10,857)	0	0	($17,100)
Modified Total Direct Costs (MTDC) i minus ii above.	**$35,363**	**$42,588**	**$34,421**	**$100**	**$100**	**$112,572**
Indirect (49% of MTDC)	**$17,328**	**$20,868**	**$16,866**	**$49**	**$49**	**$55,160**

Budget Justification for SF424A line items

UWRI Subaward

Subaward budget to UWRI by SF424A categories:

Costs supported by Federal contract	Year 1	Year 2	Year 3	Year 4	Year 5	Total
a. Personnel	$103,588	$106,694	$105,597	$108,765	$112,028	**$536,672**
b. Fringe Benefits	0	0	0	0	0	**0**
c. Travel	$29,400	$16,800	$17,600	$16,800	$16,800	**$97,400**
d. Equipment	0	0	0	0	0	**0**
e. Supplies	$6,400	$3,160	$3,160	$3,160	$3,160	$19,040
f. Contractual	0	0	0	0	0	**0**
g. Construction	0	0	0	0	0	**0**
h. Other	0	0	0	0	0	**0**
i. Total Direct Costs	$139,388	$126,654	$126,357	$128,725	$131,988	**$653,112**
j. Indirect Costs	$26,598	$24,699	$24,639	$25,113	$25,766	**$126,815**
Total	**165,986**	**$151,353**	**$150,996**	**$153,838**	**$157,754**	**$779,927**

Center Income (expenses) for non-federal income	Year 1	Year 2	Year 3	Year 4	Year 5	Total
7. Program Income	$53,300	$68,300	$94,650	$99,650	$133,650	**$449,550**
R&D management expenses	($8,883)	($11,383)	($15,775)	($16,608)	($22,275)	**($74,924)**
Income-dependent R&D expenses	($44,417)	($56,971)	($78,875)	($83,042)	($111,375)	**($374,626)**
Net to Center	**0**	**0**	**0**	**0**	**0**	**0**

Line item breakdown and justifications of Federal costs are provided below. Program Income and expenses are provided separate justification pages.

Line-item breakdown of subaward:

a. Personnel: Person months worked per year and salary costs shown in table below. Estimated salaries are inflated by 3% per year for cost of living.

PERSONNEL Position	Monthly Base Salary	Year 1 months / cost	Year 2 months / cost	Year 3 months / cost	Year 4 months / cost	Year 5 months / cost	Total months / cost
Co-PI, C. Rowney	$13,505	6.5 / $87,783	6.5 / $90,416	6.5 / $93,128	6.5 / $95,922	6.5 / $98,800	**32.5 / $466,049**
Senior Person, B. Urbonas	$13,505	0.5 / $6,753	0.5 / $6,966	0.5 / $7,164	0.5 / $7,379	0.5 / $7,600	**2.5 / $35,851**
Senior Person, L. Pechacek	$10,000	0.5 / $5,000	0.5 / $5,150	0.5 / $5,305	0.5 / $5,464	0.5 / $5,628	**2.5 / $26,547**
Senior Person, Jones	$13,505	0.3 / $4,052	0.3 / $4,173	0	0	0	**0.6 / $8,225**
Total		**7.8 / $103,588**	**7.8 / $106,694**	**7.5 / $105,597**	**7.5 / $108,765**	**7.5 / $112,028**	**38.1 / $536,672**

b. Fringe Benefits: UWRI operates as a non-profit corporation and includes fringe benefits as part of the overhead rate.

c. Travel: Travel below is for all participants in the project that are coordinated through UWRI.

Travel overview: Trip breakdowns by year are in additional tables below.

TRAVEL	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Cincinnati and/or Wash. D.C. to meet with EPA collaborators and/or project officer	$4,000	$4,000	$4,000	$4,000	$4,000	**$20,000**
Denver or Austin – technical team meetings	$6,000	$2,000	$2,000	$2,000	$2,000	**$14,000**
Denver, Austin – Project management travel	$3,000	$2,000	$2,000	$2,000	$2,000	**$11,000**
US locations for community outreach and conferences (WEF, AWWA, ASCE, NACWA)	$8,400	$4,800	$5,600	$4,800	$4,800	**$28,400**
International (destination TBD) for outreach, research collaboration, and conferences	$8,000	$4,000	$4,000	$4,000	$4,000	**$24,000**
Total	**$29,400**	**$16,800**	**$17,600**	**$16,800**	**$16,800**	**$97,400**

TRAVEL Year 1 Location and purpose	**# trips**	**# people per trip**	**# nights per trip**	**# ground transport days per person per trip**	**air fare per person per trip**	**car, taxi, ground trans. per person per trip**	**meals and lodging per person per night per trip**	**total cost**
Cincinnati and/or Wash. D.C. to meet with EPA collaborators and/or project officer	2	2	1	2	$600	$100	$200	**$4,000**
Denver or Austin – technical team meetings	2	3	1	2	$600	$100	$200	**$6,000**
Denver, Austin – Project management travel	3	1	1	2	$600	$100	$200	**$3,000**
US locations for community outreach and conferences (WEF, AWWA, ASCE, NACWA)	3	2	3	2	$600	$100	$200	**$8,400**
International (destination TBD) for outreach, research collaboration, and conferences	2	2	3	2	$1200	$100	$200	**$8,000**
Total for Year 1	**12**	**10**	**9**	**10**				**$29,400**

TRAVEL Year 2 **Location and purpose**	**# trips**	**# people per trip**	**# nights per trip**	**# ground transport days per person per trip**	**air fare per person per trip**	**car, taxi, ground trans. per person per trip**	**meals and lodging per person per night per trip**	**total cost**
Cincinnati and/or Wash. D.C. to meet with EPA collaborators and/or project officer	2	2	1	2	$600	$100	$200	**$4,000**
Denver or Austin – technical team meetings	1	2	1	2	$600	$100	$200	**$2,000**
Denver, Austin - Project management travel	2	1	1	2	$600	$100	$200	**$2,000**
US locations for community outreach and conferences (WEF, AWWA, ASCE, NACWA)	2	2	2	2	$600	$100	$200	**$4,800**
International (destination TBD) for outreach, research collaboration, and conferences	1	2	3	2	$1200	$100	$200	**$4,000**
Total for Year 2	**8**	**9**	**9**	**10**				**$16,800**

TRAVEL Year 3 **Location and purpose**	**# trips**	**# people per trip**	**# nights per trip**	**# ground transpo rt days per person per trip**	**air fare per person per trip**	**car, taxi, ground trans. per person per trip**	**meals and lodging per person per night per trip**	**total cost**
Cincinnati and/or Wash. D.C. to meet with EPA collaborators and/or project officer	2	2	1	2	$600	$100	$200	**$4,000**
Denver or Austin – technical team meetings	1	2	1	2	$600	$100	$200	**$2,000**
Denver, Austin - Project management travel	2	1	1	2	$600	$100	$200	**$2,000**
US locations for community outreach and conferences (WEF, AWWA, ASCE, NACWA)	2	2	3	2	$600	$100	$200	**$5,600**
International (destination TBD) for outreach, research collaboration, and conferences	1	2	3	2	$1200	$100	$200	**$4,000**
Total for Year 3	**8**	**9**	**9**	**10**				**$17,600**

TRAVEL Year 4 **Location and purpose**	**# trips**	**# people per trip**	**# nights per trip**	**# ground transpo rt days per person per trip**	**air fare per person per trip**	**car, taxi, ground trans. per person per trip**	**meals and lodging per person per night per trip**	**total cost**
Cincinnati and/or Wash. D.C. to meet with EPA collaborators and/or project officer	2	2	1	2	$600	$100	$200	**$4,000**
Denver or Austin – technical team meetings	1	2	1	2	$600	$100	$200	**$2,000**
Denver, Austin - Project management travel	2	1	1	2	$600	$100	$200	**$2,000**
US locations for community outreach and conferences (WEF, AWWA, ASCE, NACWA)	2	2	2	2	$600	$100	$200	**$4,800**
International (destination TBD) for outreach, research collaboration, and conferences	1	2	3	2	$1200	$100	$200	**$4,000**
Total for Year 4	**8**	**9**	**8**	**10**				**$16,800**

TRAVEL Year 5 Location and purpose	# trips	# people per trip	# nights per trip	# ground transport days per person per trip	air fare per person per trip	car, taxi, ground trans. per person per trip	meals and lodging per person per night per trip	total cost
Cincinnati and/or Wash. D.C. to meet with EPA collaborators and/or project officer	2	2	1	2	$600	$100	$200	**$4,000**
Denver or Austin – technical team meetings	1	2	1	2	$600	$100	$200	**$2,000**
Denver, Austin - Project management travel	2	1	1	2	$600	$100	$200	**$2,000**
US locations for community outreach and conferences (WEF, AWWA, ASCE, NACWA)	2	2	2	2	$600	$100	$200	**$4,800**
International (destination TBD) for outreach, research collaboration, and conferences	1	2	3	2	$1200	$100	$200	**$4,000**
Total for Year 5	**8**	**9**	**8**	**10**				**$16,800**

d. Equipment: No special equipment will be purchased for use in this research subaward.

e. Supplies: Funds requested for computer supplies and software including RAD studio, Intel FORTRAN, SSL certificates.

SUPPLIES	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
Computer supplies and software	$6,400	$3,160	$3,160	$3,160	$3,160	$19,040

f. Contractual: No contractual costs are anticipated on this subaward.

g. Construction: No construction costs are anticipated on this subaward.

h. Other: No other costs are anticipated on this subaward.

i. Total direct costs: Includes all of a-h above.

j. Indirect Costs: Indirect costs (see table below) are calculated at 20% of the Modified Total Direct Costs (MTDC). MTDC for UWRI exclude software purchases.

INDIRECT COSTS	Year 1	Year 2	Year 3	Year 4	Year 5	Total Cost
i. Total Direct Costs	$139,388	$126,654	$126,357	$128,725	$131,988	$653,112
ii. (Software)	($6,400)	($3,160)	($3,160)	($3,160)	($3,160)	($19,040)
Modified Total Direct Costs (MTDC) i minus ii above.	**$132,988**	**$123,494**	**$123,197**	**$125,565**	**$128,828**	**$653,112**
Indirect (20% of MTDC)	**$26,598**	**$24,699**	**$24,639**	**$25,113**	**$25,766**	**$126,815**

7. Program Income: See separate justification sheet for Program Income.

Ben R. Hodges, Ph.D.

Role on Project:	**Lead PI** **Model Development Expert**
Education:	Ph.D. 1997 Stanford University

Expertise
Numerical modeling Environmental fluid mechanics Open channel hydraulics and piping Collaborative model development

Dr. Hodges is the Associate Director for the Center for Research in Water Resources at the University of Texas at Austin and an Associate Professor in the Department of Civil, Architectural, and Environmental Engineering. Dr. Hodges works in the development of innovative numerical methods for problems in environmental fluid mechanics. His motivating idea is that other engineering disciplines have taken different approaches from hydraulic engineering, and we can significantly improve our models by reaching across disciplinary boundaries and adapt other approaches. His recent experience with IBM has produced a book (http://bit.ly/1eNGbzG) on cross-disciplinary collaboration between electrical and hydraulic engineers

Selected Projects

- **Simulation Program for River Networks (SPRINT).** In collaboration with computer engineer Dr. Frank Liu of IBM, Dr. Hodges developed an approach to translate modeling techniques used for microchip design to river network modeling, with dramatic speed-up of model performance.
- **Climate-Aware Renewable Hydropower Generation and Disaster Avoidance.** This NSF-sponsored collaboration with electrical engineering professors at Carnegie Mellon Univ, University of Southern California, and a civil engineering professor at Penn State University is developing new approaches to understand how run-of-the river hydropower affects both rivers and the electrical network.
- **Foundations for up-scaling multi-dimensional river hydrodynamic models to the watershed scale.** This NSF project has developed new insights into river modeling that inspired the SPRINT model development with IBM (above).
- **Integrating next-generation models into the oil spill prediction system for Texas bays.** This project is developing a modeling system that integrates hydrodynamic models, forecast data downloaded automatically from the internet, and visualization output through Google Maps and Google Earth. This system makes possible real-time oil spill prediction for emergency managers.
- **Evaluating Hydrodynamic Uncertainty in Oil Spill Modeling.** This project developed methods for estimating contributions of evolving forecasts to the uncertainty in predicted oil spills.
- **Nueces Delta Restoration Study.** This project resulted in development of the Fine Resolution Environmental Hydrodynamic model (Frehd) to study the combined landscape and channelized flow in the complex salt and freshwater marshes of the Nueces Delta.
- **Barton Springs Hydrodynamic Study.** The Frehd model is being used to evaluate changes in the dam structure for Barton Springs in light of issues with endangered species that have limited velocity habitats.

Selected Publications

Wescoat, J.L., X. Cai, G.M. Kondolf, **B.R. Hodges**, S.B. Joye, W.M. Lewis, L.A. Shabman, E. van Beek, *Delta Waters: Research to Support Integrated Water and Environmental Management in the Lower Mississippi River*, National Academies Press, 2013, 140 pgs. http://www.nap.edu/catalog.php?record_id=18484

Brezonik, P.L. ,M.S. Fennessy, **B.R. Hodges**, J.R. Karr, M.S. Peterson, J. L. Pinckney, J.I. Restrepo, R.C. Steiner, J.C. Stevenson, *Review of the St Johns River Water Supply Impact Study*, National Academies Press, 2011, 160 pgs. ISBN-13: 978-0-309-22567-0

Hodges B R. (2009) "Hydrodynamical Modeling." In: Gene E. Likens, (Editor) *Encyclopedia of Inland Waters*. volume 1, pp. 613-627 Oxford: Elsevier. http://dx.doi.org/10.1016/B978-012370626-3.00088-0

Hou, X. and **B.R. Hodges** (2014), "Integrating Google Maps/Earth in an automated oil spill forecast system," submitted to *Marine Technology Society Journal* (Feb. 2014).

Hou, X., **B.R. Hodges**, S. Negusse and C. Barker (2014), "A multi-model Python wrapper for operational oil spill transport forecasts," submitted to *Computational Science & Discovery* (Jan. 2014).

Hodges, B.R. (2014), "A new approach to the local time stepping problem for scalar transport," accepted by *Ocean Modelling* (Jan. 2014).

Liu, F. and **B.R. Hodges**, (2014) "Applying microprocessor analysis methods to river network modeling," *Environmental Modelling & Software*. 52:234-252. http://dx.doi.org/10.1016/j.envsoft.2013.09.013

Hodges, **B.R.** (2013) "Challenges in continental river dynamics," *Environmental Modelling & Software* 50:16-20. DOI 10.1016/j.envsoft.2013.08.010

Brookes, J.D., K. R. O'Brien, M.A. Burford, D. A. Bruesewitz, **B.R. Hodges**, C. McBride, and D.P. Hamilton (2013), "Diurnal vertical mixing and stratification, and effects on phytoplankton productivity in geothermal Lake Rotowhero, New Zealand," *Inland Waters*, 3:3:369-376.

Li, R., **B.R. Hodges,** X. Yong and J. Feng (2013), "A Comparison of Supersaturated Total Dissolved Gas Release with Dissolved Oxygen Release and Reaeration" *Journal of Environmental Engineering*, 139:3:385-390. DOI 10.1061/(ASCE)EE.1943-7870.0000598

Hodges, B.R. and J.E. Furnans and P.S. Kulis (2011), "Case Study: A thin-layer gravity current with implications for desalination brine disposal," *Journal of Hydraulic Engineering*, 137:3:356-371. DOI: 10.1061/(ASCE)HY.1943-7900.0000310.

Wadzuk, B.M., and **B.R. Hodges** (2009), "Hydrostatic versus nonhydrostatic Euler-Equation modeling of nonlinear internal waves," *Journal of Engineering Mechanics*, 135:10:1069-1080. DOI: 10.1061/(ASCE)0733-9399(2009)135:10(1069)

Fu, S. and **B.R. Hodges** (2009), "The time-centered split-implicit time-marching method for nonlinear advection," *Journal of Engineering Mechanics*, 135:4:256-265. DOI: 10.1061/(ASCE)0733-9399(2009)135:4(256)

Hodges, B.R. and F.J. Rueda (2008), "Semi-implicit two-level predictor-corrector methods for non-linearly coupled, hydrostatic, barotropic/baroclinic flows," *International Journal of Computational Fluid Dynamics*, 22:9:593-607. DOI: 10.1080/1061856080235338

Michael Barrett, Ph.D., PE, D.WRE

Role on Project:	**co-PI** **Stormwater Expert**
Education:	Ph.D. 1996, Civil/Environmental Engineering, University of Texas

Expertise

Regulatory Compliance
Green Infrastructure
Stormwater Monitoring
Water Quality Data Analysis

Dr. Barrett is a Professor of Civil Engineering at the University of Texas at Austin. His research interests are focused on the management of urban and construction site stormwater runoff. His projects involved the statistical analysis of water quality data and the evaluation of structural and nonstructural best management practices. Dr. Barrett is a member of the ASCE Urban Water Resources Research Council and the Hydrology, Hydraulics, and Water Quality Committee of the Transportation Research Board.

Selected Projects

- **Author, Edwards Aquifer Technical Guidance Manual: RG-348, TCEQ.** Developed a technical guidance manual for TCEQ to specify how new development within the Edwards Aquifer contributing and recharge zones can meet proposed performance standards. The manual specifies BMP selection and design criteria as well as appropriate maintenance procedures. Methodologies and examples were developed to guide engineers and planners through the BMP sizing and design process.
- **Author, Optional Enhanced Measures for the Protection of Water Quality in the Edwards Aquifer: TCEQ.** Developed a technical guidance manual for TCEQ and USFWS to specify guidelines for land development activities over the Edwards Aquifer contributing and recharge zones that result in "no take" of selected endangered aquatic species.
- **Water Quality Expert, Preliminary Engineering and Environmental Services for the MoPac South Project: CTRMA.** Providing guidance related to stormwater management, compliance with the Edwards Rules, and protection of endangered species for the potential expansion of MoPac from Lady Bird Lake to Slaughter Lane in Austin.
- **Principal Investigator, Low Impact Development (LID) Workshop Training, TCEQ.** This 319(h) project funded by the USEPA and TCEQ provides LID workshops in seven locations across Texas, including San Antonio and Austin. The objective was to identify and remove regulatory constraints to LID development in municipal land development codes. All the workshops were held in municipalities located in the watersheds of 303(d) listed waterbodies.
- **Principal Investigator, Measuring and Removing Dissolved Metals from Storm Water in Highly Urbanized Areas, NCHRP.** The objectives of this project funded by the National Highway Cooperative Research Program included developing monitoring protocols to accurate characterize the low concentrations of dissolved metals in highway runoff and the development of at least two prototype treatment systems that will allow DOTs to achieve water quality standards. .
- **Principal Investigator, Performance of Stormwater Filtration Systems, Austin, TX:** Project funded by the City of Austin to evaluate the performance of existing stormwater treatment facilities and to perform laboratory experiments to develop design standards for biofiltration systems. Factors evaluated include filter media composition, plant type, and hydraulic loading rate.
- **Principal Investigator, Performance of Natural Vegetated Areas for Reducing Pollutants in Stormwater, Austin, TX** This study, which is funded by a local developer, includes installation of field monitoring equipment to assess the benefits of dispersing stormwater over natural areas on the Glen Rose Limestone.

- **Principal Investigator, Water Quality Performance of Permeable Friction Course on Curbed Sections of Highways, TxDOT**. TxDOT has funded this project to investigate whether the water quality improvement observed on rural highways with porous asphalt overlays can also be realized on highways in urban areas with curbs and gutters. Water quality monitoring occurring on several sites on the MoPac Expressway in Austin to evaluate the impact.

Selected Publications

Barrett, M., Limouzin, Maelle, and Lawler, Desmond, Effects of media and plant selection on biofiltration performance, American Society of Civil Engineers Journal of Environmental Engineering, Vol. 139, No. 4, pp 462-470, April 2013.

Eck, Bradley, Winston, R., and Hunt, W., **Barrett, M.**, Water quality of drainage from permeable friction course, American Society of Civil Engineers Journal of Environmental Engineering, Vol. 138, No. 2, pp. 174 – 181, February 2012.

Barrett, M., Comparison of BMP performance using the International BMP Database, American Society of Civil Engineers Journal of Irrigation and Drainage Engineering, Vol. 134, No. 5, pp. 556-561, September/October, 2008.

Lampe, L., **Barrett, M.,** Woods-Ballard, B., Andrews, A., .Martin, P., Glass, C., Weinstein, N., and Jefferies, C., Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems: Final Report 2005, Water Environment Research Foundation Project 01-CTS-21T, Alexandria, VA. 225 p., 2005.

Takamatsu, M., **Barrett, M**., and Charbeneau, R., A hydraulic model for sedimentation in stormwater detention basins, American Society of Civil Engineers Journal of Environmental Engineering, Vol. 136, No. 5, pp. 527-534, May 2010.

Barrett, M., Performance comparison of structural stormwater BMPs, Water Environment Research. Vol. 77, No. 1, pp. 78-86, January/February. 2005.

Barrett, M., Lantin, Anna, and Austrheim-Smith, Steve, Stormwater pollutant removal in roadside vegetated buffer strips, Transportation Research Record No. 1890, pp. 129-140, 2004.

Barrett, M. Performance, cost and maintenance requirements of Austin sand filters, American Society of Civil Engineers Journal of Water Resources Planning and Management, Vol. 129, No. 3, pp. 234-242, May 2003.

Li, Ming-Han and **Barrett, M.**, Relationship between antecedent dry period and highway pollutant: conceptual models of buildup and removal processes, Water Environment Research, Vol. 80, No. 8, pp. 740-747, August, 2008.

Barrett, M., Comparison of BMP performance using the International BMP Database, American Society of Civil Engineers Journal of Irrigation and Drainage Engineering, Vol. 134, No. 5, pp. 556-561, September/October, 2008.

Sejkora, P. Kirisits, M.J., and **Barrett, M.**, Colonies of cliff swallows on highway bridges: point sources of fecal indicator bacteria in surface waters, Journal American Water Resources Association, 1-10. DOI: 10.1111/j.1752-1688.2011.00566.x, 10 p., August, 2011

Mendez, C., J. Brandon Klenzendorf, Brigit R. Afshar, Mark T. Simmons, **Barrett, M.,** Kerry A. Kinney, and Mary Jo Kirisits, The effect of roofing material on the quality of harvested rainwater, Water Research Vol. 45, No. 5, pp. 2049-2059, February, 2011.

Fernanda Leite, Ph.D.

Role on Project:	**Co-PI** **Building/Civil Information Modeling Expert**
Education:	Ph.D. 2009 Carnegie Mellon University

Expertise

Building/Civil Information Modeling
Design and Construction Collaboration and Coordination Technologies
Visualization and Information Modeling in Engineering Design and Construction

Dr. Leite is an Assistant Professor in Construction Engineering and Project Management in the Department of Civil, Architectural, and Environmental Engineering at the University of Texas at Austin. Dr. Leite works in the area of building information modeling. Her motivation is developing digital representations of the physical world, which can enable a broader vision of smart cities. In the shorter term, engineers will be able to develop more efficient, data-driven, construction processes. Leite's design coordination research, as well as her construction safety 4D visualization work have been featured in Engineering New-Record (ENR). Also, her work in the Digital Austin effort will be presented in the 2015 South by Southwest (SXSW) UT-Village event.

Selected Projects

- **Process-Aware Building Information Modeling for Knowledge Discovery in Multidisciplinary Design Coordination**. The objective of this research is to elicit BIM-based design coordination and construction process knowledge, exploring multiple communication methods and collaboration platforms, then formalize expert tacit knowledge, through technology-supported information capture and representation, with the intent of constructing a large database of design conflicts and related solutions. Once the knowledge is formalized, heuristics will be developed to reason about formal design and construction knowledge to mine and learn from large databases of formalized design coordination and construction process knowledge.
- **4-Dimensional Process-aware Site-specific Construction Safety Planning**. Construction remains the second most hazardous industry especially due to the dangerous combination of pedestrian workers and heavy construction vehicles and machinery, such as dump trucks, dozers, and rollers. Although the majority of hazards are generated from specific site conditions, current safety planning activities lack site-specific information and, consequently, potential site-specific hazards are not identified and safety personnel cannot effectively minimize or eliminate jobsite hazards. The objective of this research is to systematically formalize the construction safety planning process in a 4-dimentional (4D, which is a 3D BIM integrated with a construction schedule) environment to address site specific temporal and spatial safety information.
- **Generating as-built 3D models of roads and bridges from 2D photos**. Images taken from digital cameras are being widely used for construction monitoring purposes such as, to check conformance to baseline project schedules and contract specifications. Another emerging use of these photos is to generate 3D point clouds of a construction project, superimpose them on the original 3D models and check the resulting model for progress and deviations from the original plan. The objective of this Texas Department of Transportation-sponsored research is to develop a set of guidelines for taking such photographs which can enable efficient and effective generation of such 3D point clouds using off-the-shelf software packages for construction monitoring and infrastructure asset management purposes. A section of a cable

stayed bridge under-construction in Dallas, Texas, as well as an existing building in Austin, Texas, are used as testbeds for this research.

- **Guide for Civil Integrated Management (CIM) in Departments of Transportation**. This National Cooperative Highway Research Program-funded and collaborative research with the University of Colorado, Boulder aims at leveraging concepts of Building Information Modeling and applying them to Civil Infrastructure, specifically in transportation projects. The objective is to develop a guide for CIM for departments of transportation across the United States.
- **Enhanced Work Packaging: Design through Work Face Execution**. Work packaging has widely been endorsed as an effective method of planning for and managing project deliverables, whether they are engineering drawings or field installations. Put simply, work packages are the translation of abstract schedules to physical deliverables. Despite their importance, the range of work packaging procedures employed in the capital projects industry is broad. This Construction Industry Institute-sponsored research aimed at identifying and documenting the most effective work packaging procedures, including organizational responsibility for work package definition, quantification of the field productivity benefits obtained by effective work packaging, and 3D modeling approached towards work packaging.
- **AutoCodes Project**. This Fiatech-sponsored project aims at permanently transforming the way construction project code review is conducted in North America. That plan is to make the building regulatory process faster, more uniform, and ultimately more competitive by applying advanced technology. The Fiatech AutoCodes Project focuses on delivering automated code-check technology to be used with virtual 3D construction models or Building Information Models (BIM).

Selected Publications

Hamdi, O.; **Leite, F.** (2014) "Conflicting Side of Building Information Modeling Implementation in the Construction Industry". In: ASCE Journal of Legal Affairs and Dispute Resolution in Engineering and Construction. DOI: 10.1061/(ASCE)LA.1943-4170.0000137

Wang, L.; **Leite, F.** (2014) "A Process-Oriented Approach of Teaching Building Information Modeling in Construction Management". In: ASCE Journal of Professional Issues in Engineering Education and Practice. DOI: 10.1061/(ASCE)EI.1943-5541.0000203

Choe, S.; **Leite, F.**; Caldas, C. (2014) "Evaluation of Sensing Technology for the Prevention of Back-over Accidents in Construction Work Zones". In: Journal of Information Technology in Construction (ITCon), Volume 19, pp. 1-19.

Leite, F. (2014) "Impacting Novice BIM-based Design Coordination Performance through Knowledge Embedded Systems". In: AEC Bytes, June 12, 2014. Available at: http://www.aecbytes.com/viewpoint/2014/issue_71.html

Leite, F. (2014) "Researchers Counter Engineering Brain Drain with Learning Software". Engineering News-Record, February 19, 2014. Available at: http://enr.construction.com/technology/bim/2014/0219-researchers-counter-engineering-brain-drain-with-learning-software.asp

Wang, L.; **Leite, F.** (2014) "An Overview of Existing BIM Standards and Guidelines". A Report to Fiatech AutoCodes Project. Element 6: Project Management. Published by Fiatech. Available at:

Gerald E. Speitel Jr., Ph.D., P.E.

Role on Project:	**Senior Personnel** **EPANET Biofilm Modeling**
Education:	Ph.D. 1985 University of North Carolina at Chapel Hill

Expertise

Drinking water treatment processes
Disinfection by-products
Biological activity in distribution systems
Mathematical modeling

Dr. Speitel is the Associate Dean of Academic Affairs in the Cockrell School of Engineering and the C.W. Cook Professor in Environmental Engineering in the Department of Civil, Architectural and Environmental Engineering. Dr. Speitel's drinking water research addresses treatment and control of hazardous organic chemicals, disinfection by-products and their precursors, and biological activity in treatment processes and distribution systems. He has studied the chemistry and treatment of disinfection by-products formed during chloramination and chlorination of drinking water, the development of bioreactors for the cometabolism of chlorinated aliphatic chemicals, including trihalomethanes, and the role of haloamine chemistry and cometabolism in understanding nitrification episodes in drinking water distribution systems.

Selected Projects

- **Monochloramine Cometabolism: the Missing Link in Understanding Disinfectant Loss during Nitrification Episodes in Distribution Systems.** In collaboration with Dr. David Wahman at USEPA Cincinnati, studied the role of monochloramine cometabolism as mechanism for ammonia-oxidizing bacteria to minimize the impact of monochloramine disinfectant in drinking water distribution systems.
- **Significance of Trihalomethanes in Preventing Distribution System Nitrification in Chloraminated Waters.** This project evaluated the beneficial impact of THM cometabolism in diminishing distribution system nitrification episodes through the toxic impact of THM metabolites on ammonia-oxidizing bacteria.
- **Cometabolism of Trihalomethanes in Nitrifying Biofilters.** This project developed a biological treatment process for the cometabolism of THMs in drinking water treatment plants through the growth of ammonia-oxidizing bacteria in filter beds packed with granular activated carbon (GAC). The GAC provided both a reactive surface for the removal of monochloramine (to encourage microbial growth) and an ideal attachment surface for bacterial growth.
- **Disinfection By-Product Control During Chloramination.** This project characterized disinfection by-product formation during chloramination, especially in the presence of high bromide concentrations, and proposed approaches for minimizing formation. This project also development a comprehensive mathematical model of haloamine chemistry under drinking water conditions.
- **Surface Complexation and Dynamic Transport Modeling of Arsenic Removal on Adsorptive Media.** This project characterized arsenic sorption on metal oxides and developed a mathematical model for simulating performance of packed beds. The project focused on treatment of contaminated ground waters that serve as drinking water sources.
- **Enhanced Softening for Disinfection By-Product Precursor Removal.** This project studied the removal of disinfection by-product precursors using enhanced precipitative softening.

Selected Publications

Wahman, D.W., Speitel, G.E. Jr., and Machavaram, M.V. "A Proposed Abiotic Reaction Scheme for Hydroxylamine and Monochloramine under Chloramination Relevant Drinking Water Conditions, *Water Research* (accepted).

Maestre, J.P., Wahman, D.W. and Speitel, G.E. Jr. "Monochloramine Cometabolism by Nitrosomonas europaea under Drinking Water Conditions," *Water Research*, 47, 4701-4709, 2013.

Wahman, D.W. and Speitel, G.E. Jr. "Relative Importance of Nitrite Oxidation by Hypochlorous Acid under Chloramination Conditions," *Environmental Science and Technology*, 46(11), 6056-6064, 2012.

Wahman, D.W., Kirisits, M.J., Katz, L.E., and Speitel, G.E. Jr. "Ammonia-Oxidizing Bacteria in Biofilters Removing Trihalomethanes Are Related to *Nitrosomonas oligotropha*," *Applied and Environmental Microbiology*, 77(7): 2537-2540, 2011

Wahman, D.W., Katz, L.E., and Speitel, G.E. Jr. "Performance and Biofilm Activity of Nitrifying Biofilters Removing Trihalomethanes," *Water Research*, 45(4): 1669-1680, 2011.

Speitel, G.E., Jr., Kannappan, R., and Bayer, B.M. "Nitrification Index: a Unified Concept for Quantifying the Risk of Distribution System Nitrification," *Journal American Water Works Association*, 103(1): 69-80, 2011.

Alsulaili, A., Katz, L.E., and Speitel, G.E. Jr. "Monochloramine and Total Haloamine Decay After a Short Prechlorination Time in the Presence of Bromide," *Water Science and Technology: Water Supply*, 10(4): 512-516, 2010.

Russell, C.G., Lawler, D.F., Speitel, G.E. Jr., and Katz, L.E. "Effect of Softening Precipitate Composition and Surface Characteristics on Natural Organic Matter Adsorption," *Environmental Science and Technology*, 43(20): 7873-7842, 2009.

Russell, C.G., Lawler, D.F. and Speitel, G.E. Jr., "NOM Coprecipitation with Solids Formed during Softening," *Journal American Water Works Association*, 101(4): 112-124, 2009.

Pope, P.G. and Speitel, G.E. Jr. "Reactivity of Bromine-Substituted Haloamines in Forming Haloacetic Acids," in *Disinfection By-Products in Drinking Water: Occurrence, Formation, Health Effects and Control*, T. Karanfil, S.W. Krasner, P. Westerhoff, Y. Xie (eds.), ACS Symposium Series, 995, American Chemical Society, Washington, DC, 2008.

Fairey, J.L., Katz, L.E., and Speitel, G.E. Jr. "Monochloramine Destruction with Granular Activated Carbon in Drinking Water Filters," *Journal American Water Works Association*, 99(7): 110-120, 2007.

Wahman, D.W., Katz, L.E., and Speitel, G.E. Jr. "Modeling of Trihalomethane Cometabolism in Nitrifying Biofilters," *Water Research*, 41(2): 449-457, 2006.

Wahman, D.W., Katz, L.E., and Speitel, G.E. Jr. "Cometabolism of Trihalomethanes by a Mixed-Culture Nitrifying Biofilter," *Journal American Water Works Association*, 98 (12): 48-60, 2006.

Pope, P.G., Speitel, G.E., Jr., and Collins, M.R. "DXAA Formation Kinetics during Chloramination," *Journal American Water Works Association*, 98 (11): 107-120, 2006.

Fairey, J.L., Speitel, G.E. Jr., and Katz, L.E. "Impact of Natural Organic Matter on Monochloramine Reduction by Granular Activated Carbon: The Role of Porosity and Electrostatic Surface Properties," *Environmental Science and Technology*, 40 (13): 4268-4273, 2006

David R. Maidment, Ph.D., PE

Role on Project:	**Hydrological data systems expert**
Education:	Ph.D. 1976 University of Illinois at Urbana-Champaign

Expertise

Hydrological data systems
Geographical information systems
Water resources planning
Statistical techniques in hydrology

Dr. Maidment is the Hussein M. Alharthy Centennial Chair in Civil Engineering at the University of Texas at Austin. Dr Maidment is a specialist in surface water hydrology, and in particular in the application of geographic information systems to hydrology. In 2012, he received the Ray K. Linsley Award from the American Institute of Hydrology in recognition of his contributions in the field of Surface Water Hydrology. In 2011 he received the Ven Te Chow Award from the American Society of Civil Engineers for notable contributions in water resources engineering, hydrology and hydraulic engineering, outstanding service to the profession through application of GIS in surface water and groundwater hydrology, authoring books and research papers in water resources engineering, and mentoring of young engineers. In 2011 he received the Distinguished Alumnus Award, Civil and Environmental Engineering Alumni Association, University of Illinois at Urbana-Champaign for significant and lasting impact on teaching, research and practice in the fields of hydrology and water resource engineering, including the pioneering of geographical information systems applications in hydrology and technologies that have been adopted by national and international institutions. In 2010 he received the AWRA Award for Water Resources Data and Information Systems in recognition of his outstanding contributions to the application of Geographic Information Systems to water resources engineering and sciences. This award was also permanently renamed the David R. Maidment Award for Water Resources Data and Information Systems in honor of his many contributions to the field and his furtherance of the mission of the American Water Resources Association.

Selected Projects

- **Consortium of Universities for the Advancement of Hydrologic Science, Inc (CUAHSI).** Dr Maidment was Chairman of the CUAHSI Hydrologic Information Systems Committee from January 2001 to April 2004, whose work laid the foundation for a large NSF-sponsored project to develop a CUAHSI Hydrologic Information System for which he has served since April 2004 as the project leader. This position involves interacting with the San Diego Supercomputer Center and researchers at about a dozen US universities who are developing prototype components of this system. This is the NSF Cyberinfrastructure progam for Hydrologic Science
- **Arc Hydro.** Dr Maidment designed the widely used data model Arc Hydro, which is a customization of ArcGIS for application in water resources. He has presented an annual GIS Hydro seminar at the ESRI User Conference since 1994 which summarizes the state of the art in application of GIS to Water Resources. ESRI manufactures ArcGIS which is the world leader in Geographic Information Systems. He received ESRI's Lifetime Achievement Award in 2003 for his contributions to the application of GIS in Water Resources.

Selected Publications

Strassberg, G., N.L. Jones, D. R. Maidment, *Arc Hydro Groundwater: GIS for HydroGeology*, ESRI Press, Redlands CA 2011.

Maidment, D.R., (2002), *Arc Hydro: GIS for Water Resources*, ESRI Press, Redlands CA, 2002, 220 pages.

Maidment, D.R., and D. Djokic (2000), *Hydrologic and Hydraulic Modeling Support with GIS,* ESRI Press, Redlands CA, 232 pages.

Maidment, D.R., (Editor in Chief), (1993), *Handbook of Hydrology,* McGraw-Hill, 1424 pages. (Translated into Chinese in 2002, and distributed there by www.sciencep.com)

Chow, V.T., D.R. Maidment and L.W. Mays, (1988), *Applied Hydrology,* McGraw-Hill, New

York, 570 pages. (Translated into Spanish in 1994 as *Hidrología aplicada,* and distributed by McGraw Hill Interamericana)

Salas, F. R., Boldrini, E., Maidment, D. R., Nativi, S., and Domenico, B.: Crossing the digital divide: an interoperable solution for sharing time series and coverages in Earth sciences, Nat. Hazards Earth Syst. Sci., 12, 3013-3029, doi:10.5194/nhess-12-3013-2012, 2012.

David, Cédric H., Florence Habets, David R. Maidment and Zong-Liang Yang (2011), RAPID applied to the SIM-France model, Hydrological Processes, 25(22), 3412-3425. DOI: 10.1002/hyp.8070

David, Cédric H., David R. Maidment, Guo-Yue Niu, Zong-Liang Yang, Florence Habets and Victor Eijkhout (2011), River network routing on the NHDPlus dataset, Journal of Hydrometeorology, 12(5), 913-934. DOI: 10.1175/2011JHM1345.1

Johnson, S. L., E. S. Hersh, D. R. Maidment, and M. J. Kirisits. (2012) "Spatial and Temporal Variations in Bacterial Loading in the Copano Bay Watershed." *The Texas Journal of Science*. (in press).

Horsburgh, J.S., D.G. Tarboton, D.R. Maidment, and I. Zaslavsky, (2010) Components of an environmental observatory system, Computers and Geosciences, Elsevier, doi:10.1016

David, C. H., D. J. Gochis, D. R. Maidment, W. Yu, D. N. Yates, and Z.-L. Yang, (2009), Using NHDPlus as the Land Base for the Noah-distributed Model, Transactions in GIS, 13, 363-377. DOI: 10.1111/j.1467-9671.2009.01169.x

Goodall, J.L. and D.R. Maidment, A spatio-temporal model for river basin-scale hydrologic systems, International Journal of Geographical Information Science, Vol. 23, No. 2, pp. 233-247, 2009.

Johnson, S.L., T. Whiteaker and D.R. Maidment, (2009), A tool for automated load duration curve creation, *Journal of American Water Resources Association*, Vol. 45 No. 3, pp. 654-663.

Maidment, D.R., (2008), "Bringing Water Data Together", *ASCE Journal of Water Resources Planning and Management*, Vol. 134, No. 2, pp. 95-96

Horsburgh J. S., D. G. Tarboton, D. R. Maidment, I. Zaslavsky (2008), A relational model for environmental and water resources data, *Water Resources Research*, Volume 44, Paper W05406, doi:10.1029/2007WR006392.

Maidment, D.R., (2008), "Arc Hydro in Florida", *Florida Watershed Journal*, Vol. 1, No. 1, pp. 6-8.

Merwade, V. M., D. R. Maidment and J.A. Goff, "Anisotropic considerations while interpolating river channel bathymetry"*Journal of Hydrology, Volume 331, Issues 3-4, 15 December 2006, Pages 731-741*

Timothy I. Whiteaker, Ph.D.

Role on Project:	**Cyberinfrastructure expert**
Education:	Ph.D. 2004 University of Texas at Austin

Expertise

Geographical information systems
Cyberinfrastructure for hydrology
Code development
User support and training

Dr. Whiteaker is a Research Scientist at The University of Texas at Austin. His research interests are focused on innovative uses cyberinfrastructure and information systems to enable and conduct research in hydrologic and geophysical domains. His projects involved model integration, GIS tool development, database design, user support and training.

Selected Projects

- **Principal Investigator, Water Operations Model.** This project funded by the TCEQ uses NWS forecasts and requests submitted for permitted water withdrawals as forcing data for the RAPID river routing model, whose outputs are served via map services and displayed in an online interactive map. The map provides watermasters with a tool for assessing whether an arbitrary location in the stream network can support a requested water diversion.
- **Developer, Water Rights and Availability Projects, TCEQ.** In various projects funded by TCEQ over the past 14 years, Dr. Whiteaker has developed a number of GIS tool and techniques, including a toolset which evolved into the Arc Hydro tools now maintained by Esri, a raster-network regionalization technique for processing large grids (doi: 10.1080/13658810600965255), and the WRAP Hydro tools and WRAP Hydro data model, which define a geospatial framework for calculating parameters important in water rights analysis in Texas.
- **Developer and User Support, CUAHSI Hydrologic Information System (HIS).** This project funded by NSF developed cyberinfrasructure for sharing hydrologic data. Dr. Whiteaker contributed as a developer for two HIS desktop client applications which enabled discovery, download, and analysis of hydrologic observations data: HydroDesktop, a free and open source GIS application hosted at Codeplex; and HydroExcel, an Excel spreadsheet utilizing macros and a library of HydroObjects to query HIS web services. Dr. Whiteaker also authored user guides and led numerous workshops to train universities and international organizations in the use and implementation of HIS. Dr. Whiteaker continues to serve on the HIS Users Committee.
- **Lead Web Developer, Environmental Data Management in Support of Data Sharing.** For this EPA funded project, Dr. Whiteaker lead the development team in producing an online interactive mapping application showing nitrogen load and risk of exceeding pollutant standards for model scenarios run in a given watershed. The model is based upon Dr. Whiteaker's Schematic Processor, a tool for integrating GIS features with modular processing engines to simulate hydrologic processes (doi: 10.1111/j.1467-9671.2006.00254.x).
- **GIS Expert, Gulf of Mexico Basin Depositional Synthesis.** This industry-supported project, now in its seventeenth year, provides a comprehensive synthesis of Cenozoic and Mesozoic fill of the entire Gulf of Mexico basin. Synthesis products and original interpretations are delivered as a collection of GIS databases, maps, custom tools, and supporting reference materials. In addition to developing analysis techniques for understanding and generating project data, Dr. Whiteaker serves as tool developer, database designer, data manager, user support specialist, help author, and workshop specialist.

Selected Publications

Yang, G., E.P.H. Best, **T. Whiteaker**, A. Teklitz, and L. Yeghiazarian (2014). A screening-level modeling approach to estimate nitrogen loading and standard exceedance risk, with application to the Tippecanoe River watershed, Indiana. Journal of Environmental Management, 1: 1-10. doi:10.1016/j.jenvman.2014.01.003

Snedden, J.W., W.E. Galloway, **T.L. Whiteaker**, and P.E. Ganey-Curry (2012). Eastward shift of deep-water fan axes during the Miocene in the Gulf of Mexico: Possible Causes and Models. GCAGS Journal, 1: 131-44.

Ames, D.P., J.S. Horsburgh, Y. Cao, J. Kadlec, **T.L. Whiteaker**, and D. Valentine (2012). HydroDesktop: Web Services-Based Software for Hydrologic Data Discovery, Download, Visualization, and Analysis. Environmental Modelling & Software, 37: 146-56. doi:10.1016/j.envsoft.2012.03.013

Whiteaker, T.L., N. Jones, G. Strassberg, A. Lemon, and D. Gallup (2012). GIS-based data model and tools for creating and managing two-dimensional cross sections. Computers and Geosciences, 39: 42-9. doi: 10.1016/j.cageo.2011.06.008

Galloway, W.E., **T.L. Whiteaker**, and P. Ganey-Curry (2011). History of Cenozoic North American drainage basin evolution, sediment yield, and accumulation in the Gulf of Mexico basin. Geosphere 7.4: 938-73. doi:10.1130/GES00647.1

Muste, M., V. Merwade, D. Kim, D. Maidment, and **T.L. Whiteaker** (2010). Data Models for Multi-dimensional Representation of the River Processes. HydroLink, 4: 58-9.

Johnson, S.L., **T.L. Whiteaker**, and D.R. Maidment (2009). A Tool for Automated Load Duration Curve Creation. Journal of the American Water Resources Association, 45.3: 654-63.

Goodall, J.L., J. Horsburgh, **T.L. Whiteaker**, D.R. Maidment, and I. Zavlasky (2008). A first approach to web services for the National Water Information System. Environmental Modelling & Software, 23.4: 404-11. doi:10.1016/j.envsoft.2007.01.005

Whiteaker, T.L., D.R. Maidment, H. Gopalan, C. Patino, and D.C. McKinney (2007). Raster-Network Regionalization for Watershed Data Processing. International Journal of GIS, 21.3: 341-53. doi: 10.1080/13658810600965255

Whiteaker, T.L., D.R. Maidment, J. Goodall, and M. Takamatsu (2006). Integrating Arc Hydro Features with a Schematic Network. Transactions in GIS, 10.2: 219-37. doi: 10.1111/j.1467-9671.2006.00254.x

Whiteaker, T.L., O. Robayo, D.R. Maidment, and D. Obenour (2006). From a NEXRAD Rainfall Map to a Flood Inundation Map. Journal of Hydrologic Engineering, 11.1: 37-45.

David K. Arctur, Ph.D.

Role on Project:	**Senior Personnel Standards and Interoperability Expert**
Education:	Ph.D. 1996 University of Florida

Expertise

Information Modeling;
Relational and Object-Oriented Database Design;
Interoperability Testbed Leadership;
Open Geospatial Consortium (OGC) and ISO standards for geographic data exchange

Dr. Arctur is a Research Scientist with the Center for Research in Water Resources and the Center for Integrated Earth System Sciences at the University of Texas at Austin, and Research/Academic Advocate for the Open Geospatial Consortium (OGC).
Dr. Arctur has participated in geospatial information standards development since receiving his Ph.D. in Urban & Regional Planning. While working in software development for Esri, he coauthored a book on geospatial data modeling for numerous application areas, including water resources, land management, transportation systems, and other domains. He led international, public-private interoperability testbeds for OGC from 2008-2012, to advance and refine geographic data exchange standards. Since joining the University of Texas at Austin in 2012, he has continued to provide academic outreach for OGC, and to lead international testbeds for the development of the Global Earth Observation System of Systems (GEOSS).

Selected Projects

- **OGC Web Services Testbed 6 (2008-2009).** Dr. Arctur led this multi-threaded, collaborative testbed to advance OGC standards for data access, geoprocessing, and decision support applications. The decision support thread tested the integrated use of CityGML, IndoorGML, Web3D, and OGC web services (Web Mapping Service, Web Feature Service, Sensor Observation Service, Web Processing Service, security services), for outdoor-to-indoor surveillance and navigation. Project funding sponsors included the U.S. National Geospatial Intelligence Agency, Natural Resources Canada, and the U.S. Geological Survey.
  Overview: http://www.opengeospatial.org/projects/initiatives/ows-6;
  Final reports: http://www.ogcnetwork.net/ows6_reports;
  Demonstrations: http://www.opengeospatial.org/pub/www/ows6/web_files/ows6.html.
- **OGC Web Services Testbed 7 (2009-2010).** Dr. Arctur led this testbed, which included activity threads for multi-source sensor and data fusion; synchronizing multiple data feeds including crowd-sourced inputs; and semantic mediation among multiple databases. This project had funding from most of the same sponsors as for OWS-6.
  Overview: http://www.opengeospatial.org/projects/initiatives/ows-7;
  Demonstrations: http://www.opengeospatial.org/pub/www/ows7/web_files/OWS-7.html.
- **Water Information System Concept Development Study (2011)**. Dr. Arctur led a consulting study for OGC to advise CUAHSI on the evolution of CUAHSI HIS to utilize OGC data encodings, web services & system architectures.
  Overview: http://www.opengeospatial.org/projects/initiatives/ogcwateriscd;
  Final report: http://portal.opengeospatial.org/files/?artifact_id=44834.
- **GEOSS Architecture Implementation Pilot, phase 6 (AIP-6, 2013).** Dr. Arctur led the water theme activity for this project, which was to improve resources for discovery and access to water resource time series observations.
  Final results: http://www.ogcnetwork.net/pub/ogcnetwork/GEOSS/AIP6/index.html.

- **GEOSS AIP-7 (2014; in progress)**. Dr. Arctur led the water theme activity for continuation and extension of the GEOSS AIP-6 project from the previous year. The focus this year is on end-user applications for flood monitoring including crowd-sourced input, and flood prediction. Participants include the European Commission's Global Flood Awareness System (GloFAS), the Dartmouth Flood Observatory, regional and national water resource data agencies for New Zealand, France Geological Survey, and others.

Selected Publications

Arctur, D. K., C. Alessandrini, S. Pecora, J. Nelson, P. Salamon, Ed's. (2014), *GEOSS Architecture Implementation Pilot, Phase 6 (AIP-6) Water Services for Data and Maps*, March 2014, 30 pages: http://www.ogcnetwork.net/pub/ogcnetwork/GEOSS/AIP6/documents/SBA/Water/AIP6_Water_SBA_ER_v6.pdf

Sinha, A. K., **D. K. Arctur**, I. Jackson, L. Gundersen, Ed's. (2011) *Societal Challenges and Geoinformatics*, Geological Society of America, 2011, 191 pages, ISBN 9780813724829. http://rock.geosociety.org/Bookstore/default.asp?catID=9&pID=SPE482

Atkinson R., K. Millard, **D. K. Arctur**, "Standards Based Approaches for Cross-Domain Data Integration," *International Journal of SDI Research*, 2008, http://ijsdir.jrc.ec.europa.eu/index.php/ijsdir/article/view/62/26.

Arctur, D. K. and M. Zeiler, *Designing Geodatabases: Case Studies in GIS Data Modeling*, ESRI Press, 2004, 408 pages, ISBN 158948021X, http://amzn.to/1rTsbOR.

Christian G. Claudel, Ph.D.

Role on Project:	**Senior Personnel Wireless sensor network Expert**
Education:	Ph.D. 2010 University of California, Berkeley

Expertise

Wireless sensor networks
Control and estimation of distribute
Lagrangian (mobile) sensor systems

Dr. Claudel is an Assistant Professor at the University of Texas at Austin in the Department of Civil, Architectural, and Environmental Engineering. Dr. Claudel works in the development of innovative sensor systems for transportation and environmental sensing applications. His motivating idea is that sensing systems can only be scalable if they are cost-effective, easy to deploy and multipurpose. Novel sensing technologies such as Unmanned-aerial vehicles-based Lagrangian (mobile) sensor systems and multipurpose smart city sensors are his current focus.

Selected Projects

- **Dual Flash flood/Traffic sensor networks.** This KAUST-sponsored project has developed a new type of ultrasonic/passive infrared flash flood sensor applicable to urban environments. The sensor is capable of monitoring both traffic flow (flow, density, speed and classification) and flash floods (water level, presence and rain rate) using artificial neural network-based sensor fusion.
- **Unmanned Aerial Vehicle based Lagrangian flash flood sensing systems.** This KACST-Aerospace sponsored project resulted in the development of new sensing platforms for monitoring flash floods in desert environments using disposable Lagrangian microsensors.
- **Robust network traffic control schemes.** This project has developed new computational schemes for robustly controlling traffic on networks, when the state of traffic is modeled by a first order scalar conservation law. Using a Hamilton-Jacobi equivalent formulation, the constraints of the PDE model are shown to be linear, allowing efficient control schemes to be developed.
- **Lagrangian disposable flash flood sensing systems.** This project (in collaboration with Dr. Atif Shamim, KAUST) has developed novel low-cost, low weight (~1g) and disposable flash flood sensors. Innovative printing technologies allow the circuit boards and antennas to be printed on photo paper, reducing costs and making the sensor more environmentally friendly.

Selected Publications

M. Mousa, X. Zhang and **C. Claudel**, *Water Level Estimation in Urban Ultrasonic/Passive Infrared Flash Flood Sensors*, submitted to IEEE Transactions on Control Systems Technology, 2014

A. Dehwah, M. Mousa and **C. Claudel**, *Lessons learned on solar powered wireless sensor network deployments in urban, desert environments*, To appear, Ad Hoc Networks, 2014

M. Farouqui, **C. Claudel** and A. Shamim, *An Inkjet-Printed Buoyant 3-D Lagrangian Sensor for Real-Time Flood Monitoring*, IEEE Transactions on Antenna and Propagation 62 (volume 6), pages 3354-3359, 2014

Y. Li, E. Canepa, and **C. Claudel,** *Optimal control of scalar conservation laws using Mixed Integer Linear/Quadratic Programming: application to transportation networks* IEEE Transactions on control of Networked Systems (volume 1), pages 28-39, 2014

M. Ghommem, V. Calo and **C. Claudel**, *Micro cantilever flow sensor for small aircrafts, To appear,* SAGE journal on Vibration and Control, 2014

Y. Li, E. Canepa and **C. Claudel**, *Efficient robust control of first order scalar conservation laws using semi-analytical solutions*, Discrete and continuous dynamical systems Series S, volume 5(3), pages 525 – 542, 2013

J. Jiang and **C. Claudel**, *A wireless computational platform for distributed computing based traffic monitoring involving mixed eulerian-lagrangian sensing*, Proceedings of the 8th IEEE Symposium on Industrial Embedded Systems (SIES), 2013

E. Canepa, E. Odat, A. Dehwah, M. Mousa, J. Jiang, **C. Claudel**, *A sensor network architecture for urban traffic state estimation with mixed Eulerian/Lagrangian sensing based on distributed computing*, proceedings of the 27th Architecture of Computing Systems (ARCS) conference

M. Abdelkader, M. Shaqura, M. Ghommem, N. Collier,V. Calo and **C. Claudel**, *Optimal Multi-Agent Path Planning for Fast Inverse Modeling in UAV-Based Flood Sensing Applications*, proceedings of the 2014 International Conference on Unmanned Aircraft Systems (ICUAS), Orlando, FL

Daniel P. Ames, Ph.D., PE

Role on Project:	**co-PI** **Data and model sharing**
Education:	Ph.D. 2002 Utah State University

Expertise

Hydrological software development
Community open-source software
Model visualization
Linking models and data

Dr. Ames is an Associate Professor in Geospatial Technologies and Water Resources in the Department of Civil and Environmental Engineering at Brigham Young University. His focus is on water resources engineering and open source software systems for GIS and hydrologic data management, discovery, and sharing. Dr. Ames developed the free and open source MapWindow GIS, which is used widely as a spatial data visualization and analysis tool, and as a platform for third-party developers to extend through plugins. Dr. Ames has also created several other open source software tools and communities including DotSpatial, HydroDesktop and HydroServer Lite and will use this experience to help implement the community engagement components of the proposed Center. He is presently a Vice President of the International Environmental Modeling and Software Society (IEMSS) and is on the boards of three journals (EM&S, JoSH, and OSGeo Journal). Previously he received the Early Career Excellence Prize from IEMSS and the Idaho State University Distinguished Researcher Award.

Selected Projects

- EarthCube Building Blocks: Integrating Discrete and Continuous Data, National Science Foundation, 10/1/2013 – 9/30/2015 (with University of Texas – Austin).
- CUAHSI HydroDesktop Support, 9/1/2012 – 8/31/2015, CUAHSI.
- Prototype Tool for Integrated Climate Downscaling and Streamflow Prediction using Open Source GIS, 6/1/2013 – 5/30/2015, U.S. Bureau of Reclamation.
- World Water Online – Enabling Research to Support a Hydro-Climate Data Network for the World, 1/1/2013 – 6/1/2014, BYU, ORCA.
- The Method of Anchored Distributions (MAD): Principles and Implementation as a Community Resource, 9/12/2012 – 11/30/2014, NSF (with U.C. Berkeley).
- HydroShare: Interactive software infrastructure for sustaining collaborative community innovation in the hydrologic sciences, 9/1/2012 – 6/30/2017, NSF (with USU).
- SunShot: Development of the PVMapper GIS-Based Solar Siting Software Tool, 9/1/2012 – 8/31/2014, DOE (with Boise State).

Original Software

- MAD – Community software for enabling inverse modeling using the Method of Anchored Distributions (see mad.codeplex.com).
- HydroDesktop – This is an NSF funded element of the CUAHSI Hydrologic Information System for hydrologic data search, download, visualization and analysis (see www.hydrodesktop.org).
- Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) 4.0 – Extending and enhancing this watershed modeling system under EPA funding (see BASINSLive.org).
- MapWindow GIS Application and Programming Tools – 250,000 downloads, 9000 opt-in mailing list subscribers, users in >40 countries (see www.MapWindow.org).
- DotSpatial – Open source map visualization library for C# (see www.dotspatial.org).

Selected Publications

Hayden, S., **Ames, D**., Turner, D., Keene, T., and Andrus, D. (2014). "Mobile, Low-Cost, and Large-Scale Immersive Data Visualization Environment for Civil Engineering Applications." J. Comput. Civ. Eng., 10.1061/(ASCE)CP.1943-5487.0000428 , 05014011.

Yang, P., **Ames, D.P**., Fonseca, A., Anderson, D., Shrestha, R., and Glenn, N.F., 2014. What is the Effect of LiDAR-Derived DEM Resolution on Large-Scale Watershed Model Results? Environmental Modelling & Software, 58, 48-57.

Anderson, D., Ames, D.P., Yang, P., 2014. Quantitative Methods for Comparing Different Polyline Stream Network Models. Journal of Geographic Information System, 6(2), pp.

Baloch, M., **Ames, D. P**., Tanik, A., 2014. Hydrological impacts of climate and land use change on Namnam stream in Koycegiz watershed, Turkey: a developing country case study. International Journal of Environmental Science and Technology, http://link.springer.com/article/10.1007/s13762-014-0527-x

Fonseca, A., **Ames, D. P.**, Yang, P., Botelho, C., Boaventura, R., and Vilar, V., 2014. Watershed model parameter estimation and uncertainty in data-limited environments. Environmental Modelling & Software, 51, 84-93.

Conner, L. G., **Ames, D. P.**, and Gill, R. A., 2013. HydroServer Lite as an open source solution for archiving and sharing environmental data for independent university labs. Ecological Informatics, 18, 171-177.

Ames, D.P., Horsburgh, J.S., Cao, Y., Kadlec, J., Whiteaker, T., and Valentine, D., 2012. HydroDesktop: Web Services-Based Software for Hydrologic Data Discovery, Download, Visualization, and Analysis. *Environmental Modelling & Software*. Vol 37, pp 146-156.

Michaelis, C. and **Ames, D.P.**, Considerations for Implementing OGC WMS and WFS Specifications in a Desktop GIS. *Journal of Geographic Information System,* Vol 4 No.2., 161-167.

Panda, S.S., Steele, D.D., and **Ames, D.P.**, 2012. Precision Water Management in Corn Using Automated Crop Yield Modeling and Remotely Sensed Data. *Int'l J. of Remote Sensing Application*, 1(1), pp 11-21.

Raza, M., Weber, K., Mannel, S., **Ames, D.P.**, Pattillo, R., 2011. Geospatial analysis of tree root damage to sidewalks in southeastern Idaho. *URISA Journal* 23(1), pp 29-32.

Alexandrov, G.A., **Ames, D.P.**, Bellocchi, G., Bruen, M., Crout, N., Erechtchoukova, M., Hildebrandt, A., Hoffman, F., Jackisch, C., Khaiter, P., Mannina, G., Matsunaga, T., Purucker, S.T., Rivington, M., Samaniego, L., 2011. Technical assessment and evaluation of environmental models and software: Letter to the Editor, *Environmental Modelling & Software*, 26(3), pp 328-336.

Anderson, D. L. and **Ames, D.P.**, 2011. A method for extracting stream channel flow paths directly from LiDAR point cloud data. *Journal of Spatial Hydrology*, 11(1), pp 1-17.

Marchionni, B. and **Ames, D.P.**, 2011. A modular spatial modeling environment for GIS. *OSGeo Journal* Vol. 8, pp 54-64.

Dunsford, H. and **Ames, D.P.**, 2011, "MapWindow 6.0: an extensible architecture for cartographic symbology." *OSGeo Journal* Vol 8, pp 31-36.

Ames, D.P., Rafn, E., Van Kirk, R., and Crosby, B., 2009. Estimation of stream channel geometry in Idaho using GIS-derived watershed characteristics. *Env. Mod. & Software*, 24(3), pp 444-448.

Michaelis, C. and **Ames, D.P.,** 2009. Evaluation and implementation of OGC Web Processing Service for use in client-side GIS. *Geoinformatica*, 13(1), pp 109-120.

Emily Berglund, Ph.D., P.E.

Role on Project:	**Senior Personnel Water System Security Expert**
Education:	Ph.D. 2005 North Carolina State University

Expertise

Agent-based Modeling
Evolutionary Computation
Water Distribution System and Water Supply Design and Management
Watershed Management

Dr. Emily Berglund (formerly Emily Zechman) is an Associate Professor in the Department of Civil, Construction, and Environmental Engineering at North Carolina State University. Dr. Berglund's research develops simulation and optimization methods for water resources management to address complexities and feedbacks that emerge due to public sector interests, human behaviors, and social dimensions. Agent-based models are coupled with engineering models to simulate the adaptive behaviors of consumers and the interconnections among social and technical systems. Optimization methods are developed to identify management strategies that adapt to sociotechnical dynamics. Methods are applied for the management of water resources systems.

Selected Projects

- **WSC- Category 3: Collaborative Research: Water Sustainability under Near-term Climate Change: A cross-regional analysis incorporating socio-ecological feedbacks and adaptations.** The objective of this study is to understand and quantify the potential impacts of near-term climate change and population growth on freshwater sustainability by explicitly incorporating the feedbacks from human-environmental systems on water supply and demand in various target basins spanning Arizona to North Carolina.
- **An Agent-based Modeling Approach to Integrate Social Dimensions and Infrastructure Management for Urban Water Reuse.** This research is exploring the use of agent-based modeling to simulate the adoption of water reuse and conservation at individual lots and to simulate the interconnections and interactions between the consumers, water supply and delivery system and the effect of these interactions on water and energy use and sustainability; infrastructure system design; and system resilience.
- **An Integrated Framework for Assessing the Dynamics of Population Growth, Land Use and Climate Change for Urban Water Resources Management.** This integrated framework will provide critical insights for water utility operators and stakeholders about how the interactions of management plans with climate change, land use change, population growth, and consumer behaviors impact the long-term water supply sustainability and simulate system response predictions under alternate water shortage response plans.
- **An Agent-based Modeling Framework for Response Planning to Contamination Events for Water Utilities.** This research addresses the question "When bacteria or harmful chemicals get into drinking water pipes, how can public officials best protect residents from getting sick?" through new cross-disciplinary research methods from social science, public policy, and civil engineering.
- **BRIGE: A Complex Adaptive Systems Analysis Approach for Integrated Water Resources Sustainability.** This research uses agent-based modeling to simulate the many actors and systems involved in urban water resources management to consider adaptive management for water supply.

Selected Publications

Shafiee, M. and Berglund, E. (2014). "Real-Time Guidance for Hydrant Flushing Using Sensor-Hydrant Decision Trees." Journal of Water Resources Planning and Management, 10.1061/(ASCE)WR.1943-5452.0000475, 04014079.

Rasekh, A., M.E. Shafiee, E.M. Zechman, K. Brumbelow (2014) "Sociotechnical Risk Assessment for Water Distribution System Contamination Threats" Journal of Hydroinformatics,16(3), 531-549.

Kanta, L. and E.M. Zechman (2014) "A Complex Adaptive Systems Framework to Assess Supply-side and Demand-side Management for Urban Water Resources" Journal of Water Resources Planning and Management, 140(1), 75-85.

Marchi A., ..., E.M. Zechman, et al. (+59 co-authors) (2014) "Battle of the Water Networks II (BWN-II)" Journal of Water Resources Planning and Management, 140(7), 04014009.

Giacomoni, M., L. Kanta, and E.M. Zechman (2013) "A Complex Adaptive Systems Approach to Simulate the Sustainability of Water Resources and Urbanization," Journal of Water Resources Planning and Management, 139(5), 554-564.

Shafiee, M. and E.M. Zechman (2013) "An Agent-based Modeling Framework for Sociotechnical Simulation of Water Distribution Contamination Events" Journal of Hydroinformatics 15(3), 862-880.

Zechman, E.M. (2013) "Integrating evolution strategies and genetic algorithms with agent-based modeling for flushing a contaminated water distribution system" Journal of Hydroinformatics 15(3), 798-812.

Suresh, M.A., R. Stoleru, E. Zechman, B. Shihada (2013) "On Event Detection and Localization in Acyclic Flow Networks," IEEE Transactions on Systems, Man and Cybernetics: Part A: Systems 43(3), 708-723.

Kanta, L., E.M. Zechman, and K. Brumbelow (2012) "A Multi-Objective Evolutionary Computation Approach for Redesigning Water Distribution Systems to Provide Fire Flows" Journal of Water Resources Planning and Management 138(2), 144-152.

Liu, L., E.M. Zechman, G. Mahinthakumar, S. Ranjithan (2012) "Identifying contaminant sources for water distribution systems using a hybrid method," Civil Engineering and Environmental Systems 29(2), 123-136.

Liu, L., E.M. Zechman, K. Mahinthakumar, S. Ranjithan (2012) "Coupling of logistic regression analysis and local search methods for characterization of water distribution system contaminant source" Engineering Applications of Artificial Intelligence 25(2), 309-316.

Zechman, E.M. (2011) "Agent-Based Modeling to Simulate Contamination Events and Evaluate Threat Management Strategies in Water Distribution Systems," Risk Analysis 31(5), 758-772.

Zechman, E.M. and S. Ranjithan (2009) "Evolutionary Computation-based Methods for Characterizing Contaminant Sources in a Water Distribution System," Journal of Water Resources Planning and Management, 135(5), 334-343, 2009, Winner of 2010 Best Research-Oriented Paper Award

Theodore G. Cleveland, Ph.D., P.E., M.ASCE, F.EWRI

Role on Project:	**co-PI; Code Development**
Education:	Ph.D. 1989, Civil Engineering, University of California, Los Angeles, CA.

Expertise

Modeling of liquid, and solid-liquid systems
Water Quality Monitoring
Code development, web-server construction, and programming

Dr. Cleveland is an Associate Professor at Texas Tech University. Combines laboratory and field methods with skill in information management, physical and computational modeling. Projects have studied groundwater, storm water, and wastewater systems. Personally constructed cluster computers and wrote software to support large-scale data processing, and has built systems to measure flows by visible and thermal image interpretation. Dr. Cleveland is a member of the ASCE Urban Water Resources Research council.

Selected Projects

- ***New Rainfall Coefficients*:** A TxDOT project to update the intensity-duration-frequency coefficients used for drainage design in Texas. The project will produce two software products **EBDLKUP-NEW**, and **TXHYETO** a pair of design tools to facilitate rapid estimation of design storms.
- ***Floodwise, Block B, Harris County Flood Control District:*** This project simulated watershed response using generic and semi-realistic models using the **SWMM** computation engine. The models were used to assess the effect of urbanization on drainage in Harris County. The semi-realistic models produced hydrographs that were similar to observed hydrographs without extensive calibration.
- ***Investigation of Intervention Strategies to Improve Water Quality on Country Club Bayou.*** A multi-year study of a Houston receiving stream in cooperation with Montgomery Watson Americas Inc. The work included sampling 3X per week, and development of water quality models in **QUAL2E**. The project detected sources of unintentional discharges into the bayou. Removal of these sources in cooperation with the dischargers dramatically improved the Bayou's appearance and utility.
- ***Computer Model to Investigate Operation Rules for a Wastewater Flow Splitter*** A custom-written hydraulic model for the City of Houston was used to program pumps to maintain permitted flows to two wastewater treatment plants. A two-dimensional flow model of the pump bay was constructed using **FESWMS** test the consequences of removing a weir upstream of the pump forebay.
- ***Demonstration of Remote Wireless Access to a Database for Communicating Water Quality Data.*** A proof-of-principle project to enable the Houston Department of Health and Human Services to directly access a water quality database from the field using a cellular telephone and PDA as part of a larger EMPACT study for improving water quality in Houston. The work pre-dated smart phone technology by a few years and employed substantial programming in Microsoft **ASP**.
- ***Internet and Component-Based Modeling System for Lake Water Quality and Fish Habitat Projections.*** Created a **JAVA** implementation of **MINLAKE** as well as wrapper code to allow either hybrid (client-server shared processing) or strict server-side processing. The project abstract is located at http://eng.auburn.edu/users/xzf0001/txatp.html). Joshi (2002) is the main archival document from this project.
- ***Analytical Numerical Transport System (ANTS).*** This project created a library of contaminant transport models, served via a web-browser. The models themselves were written in **JAVA**. Chuang (1998) is the main archival document from this project.

- ***Research into Production Cost Reduction by Energy Management of Houston's Surface and Groundwater System.*** Integrated **KYPIPE** and **MODFLOW** to develop pumping strategies for the Southwest Houston service area to minimize pumping energy use. A nearest neighbor address-matching algorithm was created to assign water demand; The network model was later moved to **EPANET** and is still used today.

Selected Publications

http://www.rtfmps.com/resumes/MyWebPapers/ has a complete list and downloadable copies for most of these documents.

Asquith, W.H., Herrmann, G. R., **Cleveland, T.G.** 2013 "Generalized Additive Regression Models of Discharge and Mean Velocity generally associated with Direct- Runoff Conditions in Texas: The Utility of the U.S.G.S. Discharge Measurement Database" American Society of Civil Engineers, Journal of Hydrologic Engineering, Vol. 18, No. 10, pp 1331-1348.

Rowney, A. C., **Cleveland, T.G.**, Gerth, J. G. 2011. "Information Technology in 2050" Chapter 32 in "Toward a sustainable water future : Visions for 2050" American Society of Civil Engineers; eds. W.M. Grayman, D.P. Loucks, Laurel Saito. ISBN 978-0-7844-1207-7

Cleveland, T.G. , Thompson, D.B., Fang, X., and He, X. 2008 "Synthesis of Unit Hydrographs from a Digital Elevation Model" American Society of Civil Engineers, Journal of Irrigation and Drainage Engineering, Vol. 134, No. 2, pp 212-221.

Cleveland, T.G., and Botkins, W. 2008. ``Hypothetical Watershed Modeling - Block B." Harris County Flood Control District, Research Report.

Orozco, S, and **Cleveland, T.G.**, 2007. "Evaluation of Travel Path Ratio as a Measure of Short-Circuiting Potential in Stormwater Quality Basins using Ideal Flow Modeling." in Proc. of ASCE World Environmental and Water Resources Congress, May 15-19, 2007.

Cleveland, T.G. and M. Smith. 2003. ``Demonstration of Remote Wireless Access to a Database for Communicating Water Quality Data." Final Report to Houston Department of Health and Human Services, Environmental Health Division.

Cleveland, T.G., and T. Glanton, "Hydraulic Modeling of a Sewer Flow Split Structure to Evaluate Proposed Changes" Texas Section, ASCE, Annual Spring Meeting, April 1997.

Joshi, P. 2002. Web-Based Re-Engineering of Dynamic Lake Water Quality Modeling Software, MINLAKE M.S. Thesis, Department of Civil and Environmental Engineering, University of Houston.

Chuang, Lu-Chia, 1998.``A guidance system for choosing analytical contaminant transport models." Doctoral Dissertation, Department of Civil and Environmental Engineering, University of Houston, Houston, Texas. 222p

Cleveland, T.G., Rogers, J. R., Chuang L., Yuan, D, Reddy, B. and Owens, T. 1996. Research into Production Cost Reduction by Energy Management of Houston's Surface and Groundwater System. Final Report to Planning and Operations Support, Department of Public Works and Engineering, City of Houston, Houston, TX, 178p.

Cleveland, T.G., 1994. Recovery Performance for Vertical and Horizontal Wells Using Semi-Analytical Simulation, Ground Water, Vol. 32, No. 1, pp 103-107.

Robert W. Brashear, Ph.D., PE, D.WRE, BCEE

Role on Project:	
Education:	Ph.D. 1984, Civil Engineering, Texas Tech University

Expertise

Water Quality and Quantity modeling
Enterprise Information Management
Integrated Resource Management
Water Resources Software Development

Dr. Brashear is an engineer with a broad-based background in civil, water resources, and environmental engineering. His experience includes infrastructure planning and design, water supply planning, water quality planning and permitting, environmental assessments and permitting, treatment process design, and water-related research and development.

He was responsible for the management of a water resources discipline network accounting for over 400 professionals. This included responsibility for developing and implementing a quality assurance program for the water resources discipline covering a broad range of water and environmental projects. Under these programs, product quality and client satisfaction were increased. These quality assurance programs concentrated on getting the best skills to a client's project as early as possible to better meet client expectations as well as schedule and budget.

He was also responsible for the management of an internally-funded $2 million dollar research and development program at the direction of the Chief Knowledge and Technical Officers and worked with staff to leverage these dollars on water and environmental projects for external clients with clear returns on investment. Projects were often done with key and strategic external clients as well as major agencies, including USEPA, Water Environment Research Foundation, American Water Works Research Foundation, several major colleges, Water Research Centre (UK), and Danish Hydraulic Institute (Denmark).

Selected Projects

- **Development of a Linked Receiving Water and Watershed Models to Manage Water Quality, Tarrant Regional Water District, Fort Worth, Texas**. Dr. Brashear is Project Manager for a leading-edge project to develop a water quality management toolset for the Trinity River in Fort Worth, Texas. This project updated the hydrodynamic receiving water model (CE-QUAL-W2) previously developed with the USACE and to link that with watershed models developed for the immediate project area. Those watershed models are currently being developed using the USEPA Storm Water Management Model (SWMM). The receiving water model and the watershed model will be linked so that the watershed model will forward information to the receiving water model which, in turn, will be able to show impacts of different stormwater quality management practices in the watersheds. This will allow the District and the City of Fort Worth to focus limited dollars to those practices that have the best result in protecting the high water quality in the Trinity River.
- **Development of Storm Water management Model version 5 in Collaboration with the USEPA, Cincinnati, OH**. Dr. Brashear was project manager responsible for overseeing as Collaborative Research and Development Agreement (CRADA) with USEPA's Office of Water to update the U.S. Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) from version 4 to version 5, allowing greater integration with pre- and post-processing tools.
- **Development of MIKE SWMM User Interface in Collaboration with the Danish Hydraulic Institute (DHI), Copenhagen, Denmark**. Dr. Brashear was project manager responsible for overseeing the firm's collaboration with DHI to develop a graphical user interface for version 5 of the U.S. Environmental Protection Agency (EPA) Storm Water Management Model (SWMM). The user interface, MIKE SWMM, includes pre-and post-

processing capabilities, interfacing with GIS (MOUSE and MIKE 11 GIS) to provide state-of-the-art capabilities for wet weather collection system and drainageway assessment.

- **Integrated Water Resources Project, Tarrant Regional Water District, Fort Worth, Texas**. Dr. Brashear is project manager for for a two phase study to assess optimal configuration of long-term water supply options, including assessment of risk characteristics, for the Tarrant Regional Water District. The assessment will develop a system for determining preferred strategies based on cost and risk depending on the source of water supplies available. In addition, CDM Smith will be evaluating Aquifer Storage and Recovery (ASR) and additional wastewater reuse options for the District.
- **Long Range Water Supply Plan, Dallas Water Utilities, Dallas, Texas.** Dr. Brashear is assisting the City of Dallas to coordinate with regional partners assessing long-range water supply options. These include supply options where one or more regional partners will increase the value of the supply compared to the supply being developed solely by one entity.
- **Trinity Uptown/Fort Worth Central City Environmental Assessment and Remediation, Fort Worth, Texas**. Dr. Brashear is assisting in the assessment and remediation of several properties that are a part of Trinity Uptown/Fort Worth Central City joint effort between the Tarrant Regional Water District, Trinity River Vision Authority, US Army Corps of Engineers, the City of Fort Worth, TxDOT, Tarrant County, and other stakeholders. His work includes assessment of groundwater impacts on surface water quality and long-term permitting of proposed improvements to the Trinity River system in downtown Fort Worth.
- **Balanced Vision Plan Engineering Assessment, Trinity River Corridor Project Office, City of Dallas, Texas**. Dr. Brashear assisted in the development of The Balanced Vision Plan, the final configuration and preliminary design for waterway improvements to the Trinity River floodway in downtown Dallas. The project products included an updated implementation plan with material necessary to support environmental impact studies and an upcoming US Army Corps of Engineers (USACE) Fort Worth District feasibility study on floodway improvements. The project also required coordination with an urban design consultant team hired separately by the city and was recognized with an Honor Award by the American Institute of Architects in 2007.
- **Trinity River Central City/Trinity Uptown Preliminary Design and Environmental Impact Statement, Tarrant Regional Water District, Fort Worth, Texas**. Dr. Brashear's responsibilities included assessment of ecosystem impacts, guidance of hydrologic and hydraulic modeling efforts (using unsteady HEC-RAS), assessment of permitting needs, recommendations regarding civil and structural needs to meet COE requirements, assessment of Corridor Development Certificate impacts, assessment of water quality impacts per 401(c) requirements, development of 404 permitting material, and coordination with the USACE Fort Worth District in the development of a project environmental impact statement. The project required coordination with an urban design team hired separately by the District and was recognized with an Honor Award by the Waterfront Center in 2006.
- **NPDES Stormwater Permitting, Dallas/Fort Worth Region, North Central Texas Council of Governments, Arlington, Texas**. Dr. Brashear managed a regional consulting team for NPDES stormwater permitting activities through the North Central Texas Council of Governments (NCTCOG). Through this project, a comprehensive set of products were provided to assist entities in the region in developing programs to comply with EPA's stormwater regulations.

A. Charles Rowney, Ph.D., P.Eng., D.WRE, F.EWRI

Role on Project:	**co-PI** **Water Resources Center Lead Modeler/Developer**
Education:	Ph.D. 1984, Civil Engineering, University of Ottawa

Expertise

Business Management,
Water Quality and Quantity modeling
Enterprise Information Management
Integrated Resource Management
Water Resources Software Development

Dr. Rowney will participate in this project as a member of the Center for Research in Water Resources at UT, where he holds a post of Sr. Research Fellow. Dr. Rowney's interests are focused on development and application of stormwater quality and quantity management models. His projects involve the development and application of models related to stormwater quality/quantity management, and on enterprise information and asset management. He has a proven track record in R&D program management as well as applied water resources modeling projects. Dr. Rowney is a Member of the Board, and a Fellow, of the ASCE Environmental Water Resources Institute.

Selected Projects

- **Linking BMPs to Receiving Waters, Water Environment Research Foundation.** In this major ongoing research project, as Technical Director he leads development of a watershed/ BMP/receiving water model incorporating SWMM and other tools. Interoperability is a key requirement of this software, and this has included the development of a software Framework that enables interaction of several available technologies (surface and receiving water models including SWMM, QUAHYMO, CE-QUAL-W2 and others) to interact. An element of this project was development of a model (SELECT) designed for rapid evaluation of BMP configuration, implementation and costs in developing watersheds. Also included is a comprehensive suite of statistical and graphical aids designed for effective interpretation of model results. He is the principal developer of both the Framework and the SELECT model.
- **Scientific Authority, Water Balance Model.** Oversees technical and procedural elements of a Federal/Provincial/Municipal/Industrial partnership for a cloud oriented application for watershed management, integrating watershed and BMP processes and providing on-line access to users. He wrote the engine powering the system, which provides comprehensive quality/quantity simulation capabilities for watersheds, treatment and receiving waters.
- **Lead Developer and Scientific Authority, Water Balance Model Express.** As a distinct but related project which extends the Water Balance Model, the Express project uses a different technology to allow users, specifically targeting home owners, to evaluate BMP options for their lots on line. The project enables users with little technical experience to select from a menu of BMPs, to assign sizes, and to determine with the aid of a highly visual interface which configuration of BMPs will best meet the requirements of green infrastructure plans for their area. Dr. Rowney is responsible for the calculation engine which evaluates BMP compliance with volume, area and discharge requirements for each individual lot.
- **Farm Module, SFWMD.** Dr. Rowney developed an application that integrates data from three database sources (a central Oracle repository, a central Access repository, and two local Derby databases) to calculate inspection schedules for agricultural lands overseen by the South Florida Water Management District. This application is a multi-tiered JAVA based software system that enables evaluation of trends in flows and quality by individual engineers, and management oversight of engineering inspection responses, coupled with annual reporting capabilities.
- **Everglades Restoration Program, SFWMD.** In this recent project targeted at large scale agricultural/rural/mixed watershed management, Dr. Rowney developed and deployed a

hybrid management model, including underlying FORTRAN programs mandated by Florida law and an interface developed as a client-specified JAVA application. This assembly forms the basis for water and nutrient allocation of a major (800,000 acre) region of south/central Florida lands by the South Florida Water Management District.

- **Continuing Operability Committee, National Academy.** Systematically examined the chemical demilitarization program of the US Army. He was tasked with examining and evaluating the viability and resiliency of information systems used to manage the highly secure facilities and operations processing and eliminating US chemical weapons stock piles.

Selected Publications

"Mobility in the Enterprise: A State of Practice Survey", Rowney, A.C., Walton, T., Marks, A., CIO Workshop, Amsterdam, 2013.

"Linking Stormwater BMP Systems Water Quality and Quantity Performance to Whole Life Cycle Cost to Improve BMP Selection and Design", Reynolds, S., Pomeroy, C., Rowney A.C., and Rowney, C.M., Proceedings of the 2012 World Environmental and Water Resources Congress, Albuquerque, New Mexico, May 2012.

"Toward a Sustainable Water Future Visions for 2050", Ed. Grayman, W., Loucks D.P., and Saito L.; author, Chapter 32 "Information Technology in 2050", (with Cleveland, T., Gerth, J.G.), ASCE, 2012.

"Information Technology as a Driver of Water Resources Professional Practice", Rowney A.C., Cleveland, T. and Gerth J.G., Proceedings of the 2012 World Environmental and Water Resources Congress, Albuquerque, New Mexico, May 2012.

"Implementing Asset Lifecycle Information Management: Factors Critical to Long Term Viability", Rowney A.C., Cowell, A., Luypaert, M., Walters, A., CIO Workshop, 2010.

"Multiphase Modelling of Bacteria Removal in a CSO Stream", Rowney, A.C. and O'Connor, T., Proc.of the World Environmental and Water Resources Congress, Rhode Island, 2010.

"Macro Scale Wetlands Restoration by Drainage Canal Removal – Challenges, Solutions, and Lessons Learned", Weston, D. Rowney, A.C., Copp, R., Fuxan A. and Armstrong, R.N., Proceedings of the World Environmental and Water Resources Congress, Rhode Island, 2010.

"Advanced Topics in Wet Weather Discharge Control", US EPA, Office of Research and Development, 2009. (with Pechacek, L.D., Hulley, M.E., O'Connor, T.P., and Roesner, L.A.).

"City of Austin Hydrologic Model Development and Implementation", ACR, LLC, (with Pechacek, L.D.), 2009.

"Bridging the Construction/Operations Interface: Getting Better Answers by Asking Better Questions", (with Marks, A. and Cowell, A.), CIO Workshop, 2008.

"IT Outsourcing Revisited: What Works and What Doesn't", (With Sankholkar, A. and Walters, A.M.), CIO Workshop, 2008.

"Risk and Uncertainty in Model Development and Calibration", Engineering Conferences International, Arcata, 2007.

"Evaluation of Facilities Alternatives for Spreading Stormwater Flows Overland to Promote Large Scale Wetlands Rehabilitation", ASCE World Environmental and Water Resources Congress, Tampa, 2007 (with Armstrong, R.N. and Schilling, K.)

"Application of a Multivariate Systems Model to Efficiently Reconcile Facility Placement Options in a Large Scale Wetlands Restoration Project", ASCE World Environmental and Water Resources Congress, Tampa, 2007 (with Yamouth, G.)

"Development of an Integrated Framework for Comprehensive Predictive Analysis of Wetlands Restoration and Urban Drainage Preservation", ASCE World Environmental and Water Resources Congress, Tampa, 2007 (with Lehr, V.(1st), Starnes, J. and Zhao, Y.)

Wayne C. Huber, Ph.D., P.E.

Role on Project:	**SWMM Expert**
Education:	Ph.D. 1968 Massachusetts Institute of Technology

Expertise

SWMM
Low impact development
Best Management Practices
Stormwater, sewers and CSOs

Dr. Huber will participate in this project through the Urban Watersheds Research Institute. Dr. Huber is Professor Emeritus at the School of Civil and Construction Engineering of Oregon State University. He is a primary author of the original EPA Storm Water Management Model (SWMM1-SWMM4) and brings over 45 years of experience in management of stormwater, combined sewers, and nonpoint source runoff in urban areas, including simulation modeling, database formulation, receiving water impact evaluation, and control effectiveness assessment. His many publications include documents related to best management practices (BMPs), low impact development (LID), control trade-offs, and stormwater management methodologies. He has served as principal investigator (PI) or co-principal investigator for projects sponsored by the EPA, the National Cooperative Highway Research Program (NCHRP), and the Water Environment Research Foundation (WERF) related to guidance methodology for evaluation, selection, placement, and design of BMP and LID facilities. He served as PI on a project for Seattle Public Utilities (SPU), with the goal of converting SPU's sewer modeling basis to SWMM5, with development of model input from SPU's extensive ArcGIS database. Additional research has been performed on projects sponsored by the, U.S. Army Corps of Engineers, National Science Foundation, U.S. Air Force, Federal Highway Administration, State Departments of Transportation, other federal, state and local agencies. Among many contributions to the profession, he served as chair and member of two National Research Council committees on Everglades Restoration Progress, 1998-2008.

Honors and Awards

- Life Member, American Society of Civil Engineers
- Diplomate, American Academy of Water Resources Engineers
- Chair, Executive Committee, ASCE Water Resources Engineering Division, 1998-99
- Chair, National Research Council, Committee on Independent Scientific Review of Everglades Restoration Progress, 2004-06; member 2006-2008.
- Eminent Speaker and Invited Lecture Tour, Institution of Engineers, Australia, February 1992
- Invited Speaker and Lecturer, Kyoto and Tokyo Universities, October 1998
- Kennison Lecturer, Boston Society of Civil Engineers, May 2000
- ASCE/EWRI Julian Hinds Award, May 2007

Experience

- Senior Consultant, Geosyntec Consultants, 2010-present
- Professor, Department of Civil, Construction and Environmental Engineering (School of Civil and Construction Engineering, 2008+), Oregon State University, 1991- 2009; Department Head, 1991-2000; Professor Emeritus, 2009-present
- Assistant to Full Professor of Environmental Engineering Sciences, University of Florida, 1968- 1991

Selected Publications

Bedient, P.B.,W.C. Huber and B.E. Vieux, *Hydrology and Floodplain Analysis*, Prentice-Hall Publishing Co., Upper Saddle River, NJ, First Edition, 1988; Second Edition, 1992; Third Edition, 2002; Fourth Edition, 2008, Fifth Edition 2013.

Huber, W.C., Rossman, L.A. and R.E. Dickinson, "EPA Storm Water Management Model, SWMM5," Chapter 14 in *Watershed Models*, V.P. Singh and D.K. Frevert, eds., CRC Press, Boca Raton, FL, 2006.

Huber, W.C., Cannon, L. and M. Stouder, *BMP Modeling Concepts and Simulation*, EPA/600/R-06/033, Environmental Protection Agency, Cincinnati, OH, July 2006, 148 pp. On-line at: http://www.epa.gov/ORD/NRMRL/pubs/600r06033/epa600r06033toc.pdf.

Huber, W.C., Wells, W.J., Besaw, I.K. and M.A. Leisenring, "Hydrologic Regionalisation Impacts on Wet-weather Control Selection," *Water Science and Technology*, Vol. 54, No. 6-7. 2006, pp. 485-492.

Schmitt, T.G. and W.C. Huber, "The Scope of Integrated Modelling: System Boundaries, Sub-systems, Scales and Disciplines," *Water Science and Technology*, Vol. 54, No. 6-7, 2006, pp. 405-413.

Oregon State University, Geosyntec Consultants, University of Florida, Low Impact Development Center, Inc., *Evaluation of Best Management Practices and Low Impact Development for Highway Runoff Control*, NCHRP Report 565, National Cooperative Highway Research Program, Transportation Research Board, National Academies Press, Washington, DC, 2006.

Huber, W.C., Nelson, P.O., Eldin, N.N., Williamson, K.J., and J.R. Lundy, "Environmental Impact of Runoff from Highway Construction and Repair Materials: Project Overview," *Transportation Research Record 1743*, National Academies Press, Washington, DC, 2001, pp. 1-9.

Strecker, E.W. and W.C. Huber, eds., *Global Solutions for Urban Drainage*, Proc. Ninth International Conference on Urban Drainage, Portland, Oregon, September 2002, American Society of Civil Engineers, Reston, VA, 2002 (CD-ROM). Similar citation for printed volume of Extended Abstracts.

O'Loughlin, G., Huber, W.C., and B. Chocat, "Rainfall-Runoff Processes and Modelling," *Journal of Hydraulic Research*, Vol. 34, No. 6, 1996, pp. 733-751.

Huber, W.C., "Contaminant Transport in Surface Water," Chapter 14 in *Handbook of Hydrology*, D.R. Maidment, ed., McGraw-Hill, New York, 1993.

Mr. Pankani will participate in this project through the Urban Watersheds Research Institute. Mr. Pankani is a licensed Engineer with more than 13 years of experience in software development and water resources engineering. With a strong water resources background enhanced by proficiency in several modern programing languages (including Delphi Pascal and C/C++), Mr. Pankani's competencies include excellent data management and analysis capabilities and a unique ability to understand the inner workings of surface water models at the source code level.

Dan Pankani, PE

Role on Project:	**Software Engineer**
Education:	MSE, 2013 Master of Software Engineering, Portland State University

Expertise

Software Architecture and Design
Desktop / Mobile Application Development
Water quality and quantity modeling
Geographic information systems
Data management

Selected Projects

- **Primary developer, SWMM Converters for Linking BMPs Systems Performance to Receiving Water Protection, Water Environment Research Foundation:** As part of an effort to link BMP selection and design to receiving water quality, a decision support system is being developed to link various watershed models to a BMP performance simulation module that will then be linked to various receiving water models. Currently responsible for developing a converter module for EPA's Stormwater Management Model (SWMM) that will import and export flow and constituent concentration time series to and from SWMM. Using Delphi Pascal and C as the primary programming languages as well as of the SWMM code base.
- **Primary developer, Lake Tahoe Pollutant Reduction Model (PLRM) U.S. Army Corps of Engineers.** Partnered with Northwest Hydraulic Consultants Inc. to develop a model for estimating pollutant load generation and reduction associated with land development and other activities in the Tahoe Basin. Modified SWMM by adding database support and creating a simplified interface developed in Delphi Pascal from the original SWMM source code. Data manipulation included grid-based rainfall estimation using seven gages in the Lake Tahoe watershed. The model was released in 2009 and is currently available online at: ***http://www.tiims.org/***
- **Developer, Structural BMP Prioritization and Analysis Tool (SBPAT), Heal the Bay in partnership with the City and County of Los Angeles.** A project team led by Geosyntec developed a GIS-based stormwater quality decision support tool that is currently be used to prioritize structural BMP retrofit projects and estimate the costs and load reductions associated with implementation. The SBPAT tool is intended to help watershed planners, stormwater managers, and stakeholders throughout Los Angeles County in conceptual planning of structural BMP retrofit projects and NPDES compliance assessments. Mr. Pankani was responsible for programming the interface between GIS, SWMM and a probabilistic Monte-Carlo water quality model written in FORTRAN. SBPAT is available as a free download at ***http://www.sbpat.net/***
- **Primary developer, California Stormwater Quality Association (CASQA) BMP Handbooks Web Portal, CASQA.** Designed and developed an Adobe Flex-based website which includes a stormwater best management practice (BMP) selection tool. The Portal is currently available to the public by subscription on the CASQA website: ***http://www.casqa.org/LeftNavigation/BMPHandbooksPortal/tabid/200/Default.aspx.***

- **Design Engineer, Stormwater Treatment System Design at Boeing's Plant 2 – North, The Boeing Company.** Lead a stormwater retrofit design at Boeing's Plant 2 to assist the client in meeting stringent effluent limits for dissolved metals and PCBs in discharges to the Duwamish Waterway. The design had to account for tidal fluctuations, backwater effects and deep existing pipe elevations, and included media selection, and sizing of treatment facilities within a limited existing footprint.
- **Developer, Surface Water Program Master Plan, Clackamas County Service District No. 1, Clackamas County, Oregon.** In support of the development of a stormwater master plan for Clackamas County, Oregon, a GIS-based stormwater pollutant loads model was developed. The model was then used to estimate mean annual runoff volumes, pollutant concentrations, and pollutant loads throughout County study area. The model is useful as a planning tool to evaluate land-use alternatives, and expected performance of alternative treatment best management practices (BMPs). The model was used to help target and assess potential capital improvement projects (CIPs) and stormwater retrofit projects.
- **Modeler, West Gresham Master Plan, City of Gresham, Oregon.** Performed hydrologic/hydraulic modeling for the multiple-objective Storm Drainage Master Plan for the City of Gresham. Applied the XP-SWMM model to design capital projects for both stormwater conveyance and stormwater quality projects in West Gresham. Prepared preliminary costs estimates for each capital project.
- **Modeler, City of Eugene Stormwater Master Plan, City of Eugene Oregon.** Worked with others to develop hydrologic/hydraulic models for the City of Eugene in support of the development of the City of Eugene Master Plan. The model was developed using XP-SWMM and provided volume, flow rate and storm drain capacity estimates that were previously computed using regression equations and other less accurate methods.
- **Author, NCHRP 25-20(02) Identification of Highway Runoff Management Research Needs.** Worked with others on a thorough review of literature on Highway Runoff Management. Categorized and organized over 900 highway related documents using a Microsoft Access Database. Identified and prioritized research needs. Created projects for addressing the identified research needs.

Selected Publications

Quigley, M.; Rangarajan, S.; **Pankani, D**.; Henning, D. (2008) New Directions in Real-Time and Dynamic Control for Stormwater Management and Low Impact Development . Proc 2008 World Environmental and Water Resources Congress, Ahupu'A.

Strecker, E.; Huber, W.; Heaney, J.; Bodine, D.; Sansalone, J.; Quigley, M.; Leisenring, M.; **Pankani, D**.; and Thayumanavan, A. (2005). Critical Assessment of Stormwater Treatment and Control Selection Issues. Final report to the Water Environment Research Foundation. WERF 02-SW-1.

Venner, M., Leisenring, M., **Pankani, D**., and Strecker, E. (2004). Identification of Research Needs Related to Highway Runoff Management. Final report to the National Cooperative Highway Research Program (NCHRP). Transportation Research Board (TRB), Washington, D.C.

Marcus Quigley, PE, D.WRE

Role on Project:	**Expert Input on Real Time Control in Stormwater Modeling**
Education:	M.S., 1998, Civil and Environmental Engineering, Oregon State University, Corvallis, Oregon, 1998

Expertise

Real-time monitoring and control of Stormwater systems
Hydrologic and hydraulic modeling
Water resources engineering
Research and development

Mr. Quigley will participate in this project through the Urban Watersheds Research Institute. Based in Brookline, Massachusetts, he has pioneered state of the art extensions of water resources modeling practice to include real time control, data analysis, and field data acquisition. Mr. Quigley has co-authored a number of national guidance manuals for monitoring of stormwater runoff and evaluating and designing stormwater best management practices (BMPs) for clients such as the USEPA, the National Cooperative Highway Research Program, the Water Environment Research Foundation, and the Federal Highway Administration.

Selected Projects

- **Internal Research and Development Team Leader for High Performance Green Infrastructure and Water Information Systems.** Mr. Quigley is heads internal and external research and development focused on innovative real-time control systems for surface water applications including rainwater harvesting, controlled underdrain bioretention, active green roofs, tidal marsh restoration, stormwater detention, retention, and wetland control, flood control, CSO compliance, flow diversion and splitting, and other low impact/distributed storm water designs. **The approach is uniquely characterized by a number of innovations including the treatment of civil infrastructure as an integral component of enterprise information management systems as well as deployment of SWMM as a web service in the Azure cloud as an integral component of control algorithms for the control of infrastructure.**
- **Transforming Our Cities: High Performance Green Infrastructure, WERF Innovations and Research for Water Infrastructure for the 21st Century.** Mr. Quigley is the principal investigator on this $175K research effort to pilot, model, and value the role of highly distributed real-time dynamic monitoring and control in optimizing the performance of green infrastructure. The application of conventional real-time and dynamic control and feedback systems is commonplace in industrial settings, water supply and treatment, wastewater treatment and conveyance, and CSS management; however the use of dynamic control systems in green infrastructure has been quite limited. New approaches and recent advances in information technology infrastructure as well as hardware systems and software solutions are providing the foundation for a future of ubiquitous, digitally-connected, green infrastructure. This WERF funded research seeks to change the means and methods by which we understand and control our urban environments and impact natural systems. The project is being conducted in concert with the University of Massachusetts.
- **Decentralized Stormwater Controls for Urban Retrofit and CSO Reduction Nationwide, WERF.** Mr. Quigley was a co-author of this comprehensive national research study to address the usefulness and effectiveness of decentralized controls for CSO reduction purposes.

- **Critical Assessment of Stormwater Treatment and Control Selection Issues, Water Environment Research Foundation (WERF), Nationwide.** Mr. Quigley was a primary author of a project that provides national level guidance on BMP selection and design from a combined unit processes and research data perspective. The guidance was the first such document to take a fundamental unit process engineering approach to BMP design and green storm water infrastructure.
- **US EPA Evaluation of a National Stormwater Standard, Washington, D.C.** Mr. Quigley is the project manager and technical lead for research and analysis and modeling to help U.S. EPA evaluate a potential nationwide rule for the management of post-construction stormwater runoff. The most significant aspect of the project is modeling the hydrology and water quality conditions under both the existing regulations and under the proposed rule conditions. The team is evaluating the improvements in pollutant loading reductions and the costs of alternative control strategies based on the application of green infrastructure (GI) and low impact development (LID) techniques on a nationwide basis.
- **PlaNYC CSO Green Design, New York City Department of Environmental Protection.** Technical lead for blue roof pilots and senior technical advisor for monitoring for $12M green infrastructure design demonstration project in New York City to design and install Low Impact Development stormwater designs in an ultra-urban environment for the purpose of reducing stormwater flows into the combined sewer system.
- **City of Chicago Vegetated Roof Assessment, Department of Housing and Economic Development's (DHED), Chicago, IL.** Mr. Quigley served as project director for a Vegetated Roof Assessment that is using multi-spectral satellite imagery to identify and quantify the extent and health of green roofs in the entire City of Chicago (820,000 roofs). The project team used automatic image extraction software to conduct the analysis in a repeatable and efficient manner.

Selected Publications

Quigley, M., Rangarajan, S., Pankani, D., and D. Henning, New Directions in Real-Time and Dynamic Control for Stormwater Management and Low Impact Development, Proceedings of the 2008 World Environmental and Water Resources Congress, Honolulu, Hawaii, May 12-16, 2008.

Quigley, M., "Water Information Systems – Innovative Applications of Distributed Real-Time Control and Ambient Information Systems for Storm Water and CSO Control." Invited Workshop at EPA National Risk Management Research Laboratory, December 2009.

Quigley, M. Invited Panelist on Aging Infrastructure in the United States, Tufts University, Water: Systems, Science and Society (WSSS) 2011 Symposium, "Water in 2050: The Infrastructure to Get There." April 1, 2011.

Clary, J., M. Quigley, A. Poresky, A. Earles, E. Strecker, M. Leisenring and J. Jones. 2011. "Integration of Low Impact Development into the International Stormwater BMP Database." *Journal of Irrigation and Drainage Engineering*. Vol. 137, No. 3. March.

ERIC W. STRECKER, P.E., B.C.E.E.

Role on Project:	**Advisor on Model Applications and Functions.**
Education:	M.S.E., Civil Engineering, University of Washington, 1985 B.S., Fisheries Science and B.S. Environmental Resource Engineering , Humboldt State University, Arcata, California, 1983

Expertise
Water Quality and Quantity modeling
Enterprise Information Management
Integrated Resource Management
Water Resources Software Development

Mr. Strecker will participate in this project through the Urban Watersheds Research Institute. Mr. Eric Strecker, P.E., focuses on the design, monitoring, and evaluation of sustainable stormwater best management practices (BMPs), the development of major project and watershed master plans and the overall assessment and management planning to protect aquatic resources. He has provided technical direction and assistance to public and private sector clients in stormwater master planning, National Pollutant Discharge Elimination System (NPDES) permitting, Total Maximum Daily Loads (TMDLs), surface water pollution assessment and control, and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery ACT (RCRA) surface water compliance orders for almost 30 years. He continues to advance the state of the practice by conducting as a Principal or Co-Principal Investigator applied national and local research studies on sustainable stormwater management for the U.S. EPA, U.S. Federal Highway Administration, Water Environment Research Foundation, and National Cooperative Highway Research Program, as well as state and local research efforts. Mr. Strecker has written more the 50 publications on stormwater planning, low impact development approaches, and the effectiveness of BMP technologies.

Selected Projects

- **Linking BMPs to Receiving Waters, Water Environment Research Foundation.** In this major ongoing research project, Mr. Strecker oversaw the development of BMP performance algorithms and development of code linkages between the EPA SWMM model and the overall framework. He also participated as a senior advisor to the overall project.
- ***Integrated Plan for CSO Compliance, City of Seattle, Washington.*** Mr. Strecker is assisting the City of Seattle in development of its proposed Integrated Plan for compliance with its CSO Compliance Order with the US EPA. He is overseeing Geosyntec's efforts in establishing the values of proposed stormwater controls, including green infrastructure, that would be implemented to allow the City to reschedule implementation of some of its CSO control projects that have lower overall environmental benefits. The effort includes modeling estimations of potential pollutant load, concentration, and runoff volume reductions.
- ***International BMP Database, United States Environmental Protection Agency (U.S. EPA), American Society of Civil Engineers (ASCE), Nationwide.*** **Mr. Strecker is a** Principal Investigator for a comprehensive, nationwide study of BMP effectiveness and development of the International BMP Database. Included in this study was an assessment of the protocols used to evaluate BMPs. The results, which concluded that there exist wide discrepancies in evaluating the effectiveness of BMPs, were provided to U.S. EPA headquarters. He also managed the effort to develop a detailed BMP monitoring guidance document based upon the ASCE BMP database effort. Recently, he oversaw the addition of multiple Low Impact Development/Green Infrastructure practices.
- **Critical assessment of Stormwater Treatment and Control Selection Issues**, Water Environment Research Foundation (WERF), Nationwide. Mr. Strecker recently was the Principal Investigator of a project that provides national level guidance on BMP selection and design, including Green Infrastructure from a combined unit processes and research data perspective.

- ***San Diego Creek Natural Treatment Systems Master Plan,*** *Irvine Ranch Water District, Orange County, California.* Mr. Strecker served as Project Manager for the development of San Diego Creek Natural Treatment Systems Master Plan for the Irvine Ranch Water District. The plan includes the selection, sizing and initial design of over 30 wetland treatment systems in the over 100 square mile watershed. The purpose of the plan is to meet TMDL loading limits for stormwater system discharges. This effort now included the design of a selenium treatment system. He has also served as the Principal-in-Charge for mesocosom and laboratory testing, and design of an innovative selenium and nitrate removal subsurface wetland system.
- ***Stormwater Expert Panel Facilitation and Stormwater Treatment Systems Design for Confidential Clients Duwamish Waterway and Portland Harbor.*** Served as principal–in-charge in projects to facilitate meetings with, and assemble background site information for an expert panel of stormwater researchers and practitioners for two large active facilities located on the Duwamish Waterway. Specific pollutants of concern include PCBs and metals and the prevention of recontamination of sediments. Projects included water quality data analyses, long-term continuous hydrologic modeling, stormwater treatability assessment, pilot-scale testing of biofiltration media, engineering design and compliance strategies. Project resulted in successfully changing compliance order stormwater effluent requirements. For Portland Harbor, assisted confidential client with stormwater management for a closed facility and potential stormwater management scenarios with potential remediation strategies

Selected Publications

Leisenring, M., Barrett, M., Pomeroy, C.A., Poresky, A., Roesner, L.A., Rowney, A.C., and Strecker, E. (2013). *Linking BMP Systems Performance to Receiving Water Protection - BMP Performance Algorithms.* Final report to the Water Environment Research Foundation, Alexandria, VA. WERF SWC1R06bmp.

NCHRP (2012). Guidelines for Evaluating and Selecting Modifications to Existing Roadway Drainage Infrastructure to Improve Water Quality in Ultra-Urban Areas, NCHRP Report 728, Transportation Research Board, Washington D.C. (Co-PI).

Strecker, Eric, Klaus Rathfelder, Marc Leisenring, Marcus Quigley, and Brandon Steets. 2011. "Minimizing the Potential for Sediment Recontamination and Associated Liability from Stormwater System Sources", in: E.A. Foote and A.K. Bullard (Conference Chairs), *Remediation of Contaminated Sediments—2011.* Sixth International Conference on Remediation of Contaminated Sediments (New Orleans, LA; February 7–10, 2011). ISBN 978-0-9819730-3-6, Battelle Memorial Institute, Columbus, OH. www.battelle.org/sedimentscon

Clary, J., Quigley, M., Poresky, A., Earles, A., Strecker, E., Leisenring, M., and J. Jones. 2011. Integration of Low-Impact Development into the International Stormwater BMP Database. *J. Irrigation Drainage Eng.* 137, 190 (2011); doi:10.1061/(ASCE)IR.1943-4774.0000182

Clary, J., Quigley, M. Earles, A. Leisenring, M., Strecker, E. and J. Jones, 2009. Integration of Low Impact Development Studies into the International Stormwater BMP Database, Proc. of American Society of Civil Engineers Environmental and Water Resources Institute, World Environmental and Water Resources Congress. Kansas City, Missouri, May 17–21.

Strecker, E.W., Wen-sen Chu, and D. Lettenmaier. 1987. "An Evaluation of Data Requirements for Groundwater Contaminant Transport Modeling," *Water Resources Research* 23 (3) pp. 408 – 424.

Linda D. Pechacek, P.E., D.WRE, M.ASCE

Role on Project:	Administration
Education:	M.S. 1993, Civil Engineering, University of Houston, TX

Expertise

Extensive business management experience:
Developed and implemented (4 co-permittees) TPDES stormwater management program – $3-6 Million annual budget;
TPDES Stormwater Permit Programs – Monitoring, Illicit Discharge Investigations;
Urban Drainage – traditional and LID facilities;
EPA/TCEQ 319(h) grant Tule Creek Sediment Trap Pond Analysis and Modeling QAPP.

Linda D. Pechacek is President of LDP Consultants, Inc. Ms. Pechacek's practice in water resources includes both engineering and environmental science disciplines. She has extensive experience in the development and implementation of stormwater management programs, budgets, and oversight of engineering teams conducting feasibility of pond retrofits, stormwater monitoring and field investigations. She also is experienced in the development of stormwater quality master plans for public agency clients. Ms. Pechacek is a member of the ASCE/EWRI Urban Water Resources Research Council.

Selected Projects

- ***HCFCD Pond Performance Assessment, Harris County, TX***. Project currently underway is a field sampling program to evaluate sediment build-up in a wet bottom detention basin forebay. Sediment samples were analyzed for grain size, density, and volatility, and the data was inputted into a simplified continuous simulation water balance model for analysis. Both sampling program and analysis will provide a better understanding of particle transport behavior in the forebay of a wet bottom detention basin. Expected project completion date – November, 2014.
- ***EPA/TCEQ 319(h) grant Tule Creek Sediment Trap Pond Analysis and Modeling QAPP, Aransas County, TX.*** Used QUALHYMO model to analyze the performance of a sediment trap pond prior to outfall into a bay. Modeling QAPP was developed. Proj. completed 2014.
- ***Decentralized Stormwater Controls Investigation, Austin, Texas.*** Tasks included assessing the Austin drainage complaint database, estimating impervious cover connectivity, and assisting the project team to develop a maintenance and monitoring plan for the selected decentralized stormwater control plan. Project completed 2013.
- ***Integrated Stormwater Quality Management Plan, Aransas County, Texas.*** Development of an integrated stormwater management plan to address quantity/quality concerns in Aransas County, TX (Aransas Bay watershed). The plan approach mitigated the flooding potential and helped to protect and enhance wetlands, estuaries and bays and other ecological resources. LDPC was the lead consultant responsible for developing a stormwater quality master plan for all County watersheds. LDPC analyzed the hydrologic, hydraulic and water balance characteristics of the watersheds and developed BMP recommendations, also identifying the constraints/opportunities for each proposed control. Project completed 2013.
- ***QUALHYMO BMP Tool Austin, Texas***. Assisted ACR, LLC to develop a BMP analysis tool for City of Austin staff. The tool is to effectively evaluate BMP design submittals while optimizing parameter criteria. Project completed 2010.
- ***Stormwater Quality Master Plan at IAH, Houston, Texas***. Bush Intercontinental Airport Houston – 10,000 acres with numerous drainage basins. Project evaluated existing and proposed BMPs. A water quality model was used to analyze pollutant loads and recommend BMP controls at specified locations for 2011 and 2025 scenarios. Project completed in 2009.

- ***Steering Committee Member for Bacteria TMDL Implementation Plan, Houston and Harris County.*** Appointed to "BIG" Committee in 2008 to oversee the development/ implementation of a comprehensive area-wide Implementation Plan for metro water quality limited waterways in Houston/Harris County.
- ***Two Dallas TPDES Stormwater Permit Applications/ SWPPPs, Love Field and Dallas Executive Airport, Dallas, Texas***. Technical Director - Developed SWPPPs and industrial stormwater permit applications. Project completed 2005.
- ***Implementation of National Pollutant Discharge Elimination Systems (NPDES) Permit Stormwater Management Programs, City of Houston, Harris County, Harris County Flood Control District and TxDOT Houston, Harris County, Texas.*** Ms. Pechacek directed the work tasks and maintained the quality control function for the MS4 stormwater permit requirements for 4 co-permittees. Annual program budget ranged from $3-6 million. She assisted the four co-permittees to implement their stormwater management programs for over 8 years. The TPDES MS4 permit renewal was issued by TCEQ in 2009.

Key tasks completed during her eight-year tenure implementing this joint permit and stormwater management programs included:

- Identified policy issues related to development of construction and New Development/Redevelopment programs; finalized the *Stormwater Management Handbook for* Construction *Activities* and *Stormwater Quality Management Guidance Manual*.
- Re-activated public review process using 7 member Technical Advisory Committee (TAC) to provide comments on the stormwater BMP guidance documents.
- Started up and implemented the represented monitoring program at 4 representative land use locations for the City of Houston, including development of the QAPP.
- Developed and activated a public review process that included over 40 professional and technical organizations to support the 7-member Technical Advisory Committee's review process on the City's stormwater quality ordinance and County regulations.
- Managed the development of design criteria for permanent SWQ structural controls.
- Evaluated the feasibility of various water quality retrofit studies for detention basins and drainageways for both HCFCD and TxDOT Houston.
- Developed and implemented floatables and dry/wet weather screening programs for COH and TxDOT Houston. Expanded QAPP to include these tasks.
- Developed the program to identify and track illicit discharges into the City's drainage system while interpreting field screening results.
- Assessed and tracked annual compliance with MS4 permit requirements for City, County, HCFCD and TxDOT Houston. Documented compliance progress of permit requirements.
- Managed development of training materials for public workshops to educate municipal staff of significant stormwater management elements in the new stormwater ordinance/ regulations.
- Managed the development of an industrial dischargers' database, completion of non-stormwater discharge site inventories at the City, County and HCFCD.
- Supervised the development of standardized procedures for the City's seasonal stormwater sample collection/flow calculation/manifest procedures, dry and wet weather field screening protocols, and investigations pertaining to the illicit discharges program. Included development of standardized procedures for illicit discharge investigations TxDOT Houston and performed numerous field surveys on TxDOT/ COH outfalls to identify locations of potential illicit discharges.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Ben Hodges**

Other agencies (including NSF) to which this proposal has been/will be submit-

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Hydrodynamic Modeling of Barton Springs Pool**

Source of Support: **City of Austin**

Total Award Amount: $88,130 Total Award Period Covered: 1/01/14 – 8/31/15

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: Acad: 0.0 Sumr: 0.25

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: Cybersees: Type 2: Climate-Aware Renewable Hydropower Generation and Disaster Avoidance**

Source of Support: **National Science Foundation**

Total Award Amount: $ 227,818.00 Total Award Period Covered: 9/15/13 – 8/31/16

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: Acad: 0. Sumr: 0.33

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Improving Salinity modeling methods for determining environmental inflow regimes for Nueces**

Source of Support: **Texas Water Development Board**

Total Award Amount: $ 80,000 Total Award Period Covered: 6/01/14 – 8/31/15

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: Acad: 0.20 Sumr:

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Guadalupe Estuary Bayou Flow Study**

Source of Support: **Texas Water Development Board**

Total Award Amount: $ 200,000 Total Award Period Covered: 5/01/14 – 8/31/15

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: Acad: 0. Sumr: 0.25

Support: Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: Acad: 0. Sumr: 0

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Barrett, Michael**

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Coastal Stormwater Best Mgmt Practices**

Source of Support: **Texas General Land Office**

Total Award Amount:$ 529,689 Total Award Period Covered: 2/27/2013 to 5/31/2015

Location of Project: Univ. of Texas at Austin

Person-Months Per Year Committed to the Project. 0 Cal: 1.0 Acad: Sumr:

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: Acad: Sumr:

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: Acad: Sumr:

Support: Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project: Univ. of Texas at Austin

Person-Months Per Year Committed to the Project. 0 Cal: 0.15 Acad: Sumr:

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: Acad: Sumr:

United States
ENVIRONMENTAL PROTECTION AGENCY
Washington, DC 20460

OMB Approval No. 2030-0020
Approval Expires 06/30/17

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Fernanda Leite

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: [x] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal: Guide for Civil Integrated Management (CIM) in Departments of Transportation – NCHRP 10-96

Source of Support: National Cooperative Highway Research Program (NCHRP)
Total Award Amount: 250,000.00 Total Award Period Covered: 06/01/2014 to 08/31/2015
Location of Project: The University of Texas at Austin
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.50

Support: [x] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal: RT 323 – Finding Leading Indicators to Prevent Premature Starts, and Assuring Uninterrupted Construction

Source of Support: Construction Industry Institute
Total Award Amount: 200,775.00 Total Award Period Covered: to
Location of Project: The University of Texas at Austin
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.75

Support: [ ] Current [x] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal: Demonstrating the Ability to Implement Visualization Tools to Promote Effective Participation of Environmental Justice Communities in Transportation Planning

Source of Support: Federal Highway Administration
Total Award Amount: 263,789.00 Total Award Period Covered: 01/01/2015 to 12/31/2015
Location of Project: The University of Texas at Austin
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.75

Support: [ ] Current [x] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal: CAREER: Process-Aware Building Information Modeling for Knowledge Discovery in Multidisciplinary Design Coordination

Source of Support: National Science Foundation
Total Award Amount: 500,000.00 Total Award Period Covered: 07/01/2015 to 06/30/2020
Location of Project: The University of Texas at Austin
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.75

Support: [ ] Current [x] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support
Project/Proposal: 4-Dimensional Process-aware Site-specific Construction Safety Planning

Source of Support: National Science Foundation
Total Award Amount: 205,307.00 Total Award Period Covered: 01/01/2015 to 05/31/2017
Location of Project: The University of Texas at Austin
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.75

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

EPA

United States
ENVIRONMENTAL PROTECTION AGENCY
Washington, DC 20460

OMB Approval No. 2030-0020
Approval Expires 06/30/17

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Fernanda Leite

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: An Approach to Fusing Multiple Freight Data Sources to Support Natural Language Queries

Source of Support: National Science Foundation
Total Award Amount: 356,905.00 Total Award Period Covered: 01/01/2015 to 12/31/2017
Location of Project: The University of Texas at Austin
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1.00

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

OMB Approval No. 2030-0020
Approval Expires 4/30/09

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Speitel, Gerald

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Monochloramine Cometabolism: the Missing Link in Understanding Disinfectant Loss during Nitrification

Source of Support: Water Research Foundation
Total Award Amount: 150,000.00 Total Award Period Covered: 01/01/2011 to 02/01/2015
Location of Project: UT Austin
Person-Months Per Year Committed to the Project. Cal: 0.12 Acad: Sumr:

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Water Innovation Network for Sustainable Small Systems

Source of Support: EPA
Total Award Amount: 1,456,213.00 Total Award Period Covered: 12/01/2014 to 01/31/2018
Location of Project: UT Austin
Person-Months Per Year Committed to the Project. Cal: 0.12 Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NCER FORM 5 (9/01) For Use with EPA STAR Grant Applications

USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **David R. Maidment**

Other agencies to which this proposal has been/will be submitted.

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **EarthCube Building Blocks: Integrating Discrete and Continuous Data (Awarded)**

Source of Support: **NSF**

Total Award Amount:$ 1,097,472 Total Award Period Covered: 1/01/2014-12/31/2016

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: Acad: Sumr: 1.10

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Integrated Multi-Scale Study of the Climatic Impacts on Watersheds**

Source of Support: **NASA**

Total Award Amount: $ 143,008 Total Award Period Covered: 6/01/2011-5/31/2015

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: 0.15 Acad: Sumr:

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Bridging the Digital Divide between Discreet and Continuous Space-Time Array Data to Enhance the Accessibility to and….**

Source of Support: **NASA**

Total Award Amount: $ 133,972 Total Award Period Covered: 6/01/2012-5/31/2015

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: 0.15 Acad: Sumr:

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: SI2-SSI: An Interactive Software Infrastructure for Sustaining Collaborative Community**

Source of Support: **NSF: Utah State Univ. (Lead)**

Total Award Amount: $ 146,724 Total Award Period Covered: 7/01/2012-6/30/2015

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: Acad: Sumr: 0.10

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Chukchi Sea Offshore Monitoring in Drilling Area (COMIDA): Hanna Shoal Ecosystem Study**

Source of Support: **INT-BOEMRE**

Total Award Amount: $ 69,634.00 Total Award Period Covered: 9/19/2011-8/31/2016

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: 0.15 Acad: Sumr:

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Timothy Whiteaker

Other agencies (including NSF) to which this proposal has been/will be submit-

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Bridging the Digital Divide between Discrete and Continuous Space-Time Array Data to Enhance the Accessibility to and ...**

Source of Support: **NASA**

Total Award Amount: $ 283,883 Total Award Period Covered: 6/01/2012-5/31/2015

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: 0.75 Acad: 0 Sumr:

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Collaborative Research: SI2-Ssi: An interactive software infrastructure for sustaining collaborative community**

Source of Support: **NSF (Lead: Utah State University)**

Total Award Amount: $ 146,724 Total Award Period Covered: 7/01/2012-6/30/2015

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: 0.33 Acad: 0 Sumr: 0

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **EarthCube Building Blocks: Integrating Discrete and Continuous Data**

Source of Support: **NSF**

Total Award Amount: $ 899,999 Total Award Period Covered: 9/15/2013-8/31/2015

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: 1.75 Acad: 0 Sumr: 0

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Environmental Data Management in Support of Data Sharing**

Source of Support: **EPA (Pegasus)**

Total Award Amount: $ 7,963.73 Total Award Period Covered: 7/08/2014-9/30/2018

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: 0.10 Acad: 0 Sumr: 0

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Water Operations Model**

Source of Support: **Texas Commission on Environmental Quality**

Total Award Amount: $ 100,000 Total Award Period Covered: 9/01/2014-8/31/2015

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: 0.50 Acad: Sumr: 0

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Timothy Whiteaker

Other agencies (including NSF) to which this proposal has been/will be submit-

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Chukchi Sea offshore monitoring in drilling area (COMIDA) Hanna Shoal ecosystem study**

Source of Support: **INT-BOEMRE**

Total Award Amount: $ 35,396 Total Award Period Covered: 9/01/2011-8/31/2016

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: 0.35 Acad: 0 Sumr:

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **ANIMIDA III Beaufort Sea Ecosystem Study**

Source of Support:

Total Award Amount: $ 34,997 Total Award Period Covered: 10/01/2013-11/30/2015

Location of Project: UT Austin

Person-Months Per Year Committed to the Project. 0 Cal: 0.25 Acad: 0 Sumr: 0

Support: Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: Acad: 0 Sumr: 0

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: Acad: 0 Sumr: 0

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. 0 Cal: Acad: Sumr: 0

---

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: David Arctur

Other agencies (including NSF) to which this proposal has been/will be submit-
NSF

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **EarthCube Test Enterprise Governance: An Agile Approach**

Source of Support: NSF
Total Award Amount: $27,500 Total Award Period Covered: August 1, 2013 – July 31, 2015
Location of Project: Investigator from Austin, TX, and as required, Arizona Geological Survey and workshop sites
Person-Months Per Year Committed to the Project. Cal: 1.77 Acad: Sumr:

Support: X Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **EarthCube Building Blocks: Integrating Discrete and Continuous Data**

Source of Support: NSF
Total Award Amount: $899,999 Total Award Period Covered: 9/15/2013 to 8/31/2015
Location of Project: UT Austin
Person-Months Per Year Committed to the Project. Cal: 2.0 Acad: Sumr:

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Development of Tools for access to both NASA and non-NASA Systems**

Source of Support: NASA
Total Award Amount: $61,498 Total Award Period Covered: 5/22/2014 to 5/21/2016
Location of Project: UT Austin
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99) USE ADDITIONAL SHEETS AS NECESSARY

55

United States
ENVIRONMENTAL PROTECTION AGENCY
Washington, DC 20460

OMB Approval No. 2030-0020
Approval Expires 06/30/17

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Christian Claudel

Other agencies (including NSF) to which this proposal has been/will be submitted.
None

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Bringing safety to vulnerable Texas users: leveraging smart vehicle and wireless technology

Source of Support: Texas DOT
Total Award Amount: 578,407.00 Total Award Period Covered: 01/01/2015 to 07/01/2016
Location of Project: UT Austin
Person-Months Per Year Committed to the Project. Cal: 3.00 Acad: 2.00 Sumr: 1.00

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Implications of Automated Vehicles on Safety, Design and Operation of the Texas Highway System

Source of Support: Texas DOT
Total Award Amount: 126,625.00 Total Award Period Covered: 01/01/2015 to 09/01/2016
Location of Project: UT Austin
Person-Months Per Year Committed to the Project. Cal: 1.00 Acad: 0.50 Sumr: 0.50

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: An Assessment of Autonomous Vehicles: Traffic Impacts and Infrastructure Needs

Source of Support: Texas DOT
Total Award Amount: 128,733.00 Total Award Period Covered: 01/01/2015 to 01/01/2017
Location of Project: UT Austin
Person-Months Per Year Committed to the Project. Cal: 1.00 Acad: 0.50 Sumr: 0.50

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

EPA

United States
ENVIRONMENTAL PROTECTION AGENCY
Washington, DC 20460

OMB Approval No. 2030-0020
Approval Expires 06/30/17

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Daniel P. Ames

Other agencies (including NSF) to which this proposal has been/will be submitted.
None

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: A Sustainable Center for Crowd-Sourced Water Infrastructure Modeling

Source of Support: EPA
Total Award Amount: 161,310.00 Total Award Period Covered: 01/01/2016 to 12/31/2020
Location of Project: USA
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.50

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: HydroShare: Interactive software infrastructure for sustaining collaborative community...

Source of Support: NSF
Total Award Amount: 452,189.00 Total Award Period Covered: 09/01/2012 to 08/31/2015
Location of Project: USA
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1.00

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Facilities Support: The CUAHSI Water Data Center

Source of Support: NSF
Total Award Amount: 100,000.00 Total Award Period Covered: 09/01/2012 to 08/31/2017
Location of Project: USA
Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 0.00

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Title: Design and Development of a Prototype Tool for Integrated Climate Downscaling...

Source of Support: Bureau of Reclamation
Total Award Amount: 80,515.00 Total Award Period Covered: 06/01/2013 to 05/31/2015
Location of Project: Provo, Utah
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1.00

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: EarthCube Building Blocks: Integrating Discrete and Continuous Data

Source of Support: NSF
Total Award Amount: 101,771.00 Total Award Period Covered: 01/01/2014 to 12/31/2015
Location of Project: Provo, Utah
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1.00

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

United States
ENVIRONMENTAL PROTECTION AGENCY
Washington, DC 20460

OMB Approval No. 2030-0020
Approval Expires 06/30/17

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Emily Z. Berglund

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Re-engineering the Urban Water Cycle for Human and Ecological Health

Source of Support: Environmental Protection Agency
Total Award Amount: 330,000.00 Total Award Period Covered: 01/01/2015 to 00/00/2018
Location of Project: North Carolina State University
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.50

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Rebound Effects and Water Resources Management: Evaluating Behavioral Responses to Reclaimed Water Systems and Their Impact on Infrastructure Management

Source of Support: NC Water Resources Research Inistitute
Total Award Amount: 60,000.00 Total Award Period Covered: 03/01/2015 to 02/28/2016
Location of Project: North Carolina State University
Person-Months Per Year Committed to the Project. Cal: Acad: 0.60 Sumr:

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Laboratory for Analytic Sciences - DO2 Task 3.7 - Analytic Workflow

Source of Support: National Security Agency
Total Award Amount: 52,500.00 Total Award Period Covered: 09/01/2013 to 01/01/2015
Location of Project: North Carolina State University
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.20

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Laboratory for Analytic Sciences - DO3 Task 2.8 - Analytic Workflow

Source of Support: National Security Agency
Total Award Amount: 50,000.00 Total Award Period Covered: 05/31/2014 to 01/01/2015
Location of Project: North Carolina State University
Person-Months Per Year Committed to the Project. Cal: Acad: 0.60 Sumr:

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: WSC - Category 3: Collaborative Research: Water Sustainability under Near-term Climate Change: A cross-regional analysis incorporating socio-ecological feedbacks and adaptations

Source of Support: NSF Water Sustainability and Climate
Total Award Amount: 882,581.00 Total Award Period Covered: 09/01/2012 to 09/01/2016
Location of Project: North Carolina State University
Person-Months Per Year Committed to the Project. Cal: Acad: 0.63 Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

United States
ENVIRONMENTAL PROTECTION AGENCY
Washington, DC 20460

OMB Approval No. 2030-0020
Approval Expires 06/30/17

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Emily Z. Berglund

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: Science of Security Lablet: Understanding Effects of Norms and Policies on Robustness, Liveness, and Resilience of Systems

Source of Support: National Security Agency
Total Award Amount: 184,146.00 Total Award Period Covered: 01/01/2014 to 03/31/3015
Location of Project: North Carolina State University
Person-Months Per Year Committed to the Project. Cal: Acad: 0.63 Sumr: 1.00

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: An Agent-based Modeling Approach to Integrate Social Dimensions and Infrastructure Management for Urban Water Reuse

Source of Support: NSF Civil Infrastructure Systems
Total Award Amount: 320,000.00 Total Award Period Covered: 09/01/2012 to 08/31/2015
Location of Project: North Carolina State University
Person-Months Per Year Committed to the Project. Cal: Acad: 0.60 Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

United States
ENVIRONMENTAL PROTECTION AGENCY
Washington, DC 20460

OMB Approval No. 2030-0020
Approval Expires 06/30/17

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Theodore G. Cleveland

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: New Rainfall Coefficients

Source of Support: Texas Department of Transportation
Total Award Amount: $92,253 Total Award Period Covered: 08/22/14 to 08/31/15
Location of Project: Texas Tech University
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1.0

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal: TxDOT DES 601, DES 602, and DES 606 Course Instruction: Basic Hydrology and Hydraulics; Urban Storm Drain Design; Watershed Modeling using HEC-HMS

Source of Support: Texas Department of Transportation
Total Award Amount: $126,309 Total Award Period Covered: 09/10/12 to 08/31/15
Location of Project: Texas Tech University
Person-Months Per Year Committed to the Project. Cal: 1.0 Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal:

Source of Support:
Total Award Amount: Total Award Period Covered: to
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

15 Letters of Intent/Support

Our research team decided not to provide letters of intent/support from industry. This decision is based on the idea that we would like to have a level playing field with all interested parties should the Center be awarded to our team. We believe that wherever the Center is established there will be a wide range of national and international vendors, engineering firms and multinational information technology corporations, and academics that will be interested in working with the Center. It will be in the Center and EPA's interest to have these collaboration discussion in an open and competitive framework after award of the Center rather than in closed partnership arrangements during the proposal phase. Our research team is committed to establishing a truly national and long-term Center that is open to work with all industry, government agencies, and academics – including those who are in competing proposals.